Nitrates in Surface Waters of the Rother Basin, West Sussex.

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NITRATES IN SURFACE WATERS OF THE ROTHER BASIN, WEST SUSSEX.

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ABSTRACT

The object of this thesis is to investigate the feasibility of predicting Nitrate Nitrogen concentrationsiin a river draining a rural watershed on the basis of available survey information. The survey information chosen is the set of parameters: land-use, geology,season and discharge state. Observations of a sample of 17 springs and23 field drains for 52 weeks show that high NO_3-N values are associated with arable land, areas of clay, the early winter season and with high discharge events. For springs only the effect of geology is discernable. The most notable effect is of arable land, particularly on Gault clay. These relations are tested for 10 stations on the river network using seasonal mean values which are based on 52 weekly observations. The relations are shown to be the same at the larger scale, and the variable'%area in arable use on Gault'explains over 70% of the total sum of squares of NO_3-N observations. The regression developed for 10 stations is used to predict seasonal mean values for 26 other stations. These are compared with means based on 52 weekly observations.These show that the model is unsuccessful in reproducing the effects of sewage works but is adequate in other respects. The use of a stochastic generator to reproduce weekly values is explored and rejectedbecause no suitable probability function can be found. A weekly discharge model is employed instead. This fails to reproduce antecedence effects, but the other relations are upheld at this time interval. At both the site and the basin scale this thesis shows the overriding effect of arable enterprises on Gault clay, though all the other factors individually are significant.

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PART 1

INTRODUCTION

The object of this thesis is to investigate the feasibility of predicting Nitrate Nitrogen* concentrations in a river draining an agricultural watershed, using existing information about the river and its basin.

Nitrate Nitrogen concentration is chosen as an important water quality parameter in relation to domestic and ecological uses. Nitrates are derived from two principal sources, by the oxidation of organic sewage and by the leaching of soil. It is suspected that concentrations are increasing because of changes in the behaviour of the second source (Tomlinson, 1970). This is of particular interest because, for all practical purposes, it is beyond control. Moreover, the prediction of Nitrate Nitrogen concentrations in basins dominated by the second source involves an entirely different and more complex set of problems from those dominated by the first.

It can be considered that three sorts of models can be used to predict Nitrate Nitrogen concentrations; mass balance models physical models of runoff and leaching and statistical models.

Mass balance models are appropriate where a small number of discrete sources dominate the budget. Quantitive measures are

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* In this thesis, Nitrate Nitrogen is the Nitrogen existing in the form of the Nitrate (NO_3^{--}) ion in aqueous solution and is expressed as a concentration of Nitrogen in mg per litre or p. p. m.

required of amounts and rates of Nitrate Nitrogen entering, leaving or existing within a river system. Knowledge of any two allows the third to be estimated by the continuity equation.

These models are likely to be useful therefore for urban rivers, but not for rural ones where Nitrates derive from a mult-tude of non-point sources (Owens, 1970) whose discharge cannot be measured.

One of the most ambitious attempts to model water quality is that undertaken as part of the Trent Research Programme (Newsome et al., 1972; Water Resources Board 1973; Miller and Short 1972). This involved a mass-balance model which proceeds from the headwaters of the river system to the downstream limit adding together all the inputs and discharges and considering sequentially and individually the effects on flow and water quality. Corrections are included for non-conservative parameters such as Ammoniacal Nitrogen. The Model uses annual mean values of quality variables and flow for all the calculations. Relations between mean and percentile values have been determined for all the major substances (Porter and Boon, 1971).

The use of mean annual data involves difficulties with predicting extreme conditions, such as at low flow, when mean-percentile relations may not be reliable. However, Brewin et al (1972) state that water quality conditions in the Trent can be estimated for changes in the normal calibration conditions resulting from:

increased or decreased flow from effluent treatment works;

improvement or deterioration in the quality of effluent discharges;

the use of river retention lakes;

further abstractions;

changes in use by power stations;

alterations to calibration functions and constants; and

changes in mean annual natural river flow.

This model goes a long way towards overcoming the problems associated with previous work in spite of the initial use of crude data. Problems of linearity and stationarity are overcome and water quality variables are predicted directly from information on the major sources of supply. In addition an entire basin is considered and temporal changes accommodated. The Trent Programme provides large amounts of good qualit y data which ensures the success of the predictive model.

The Trent basin is heavily populated and the river supplies water to many users as well as receiving the effluent from a large number of domestic and industrial sources. The main problems of water quality management therefore, are related to waste products received at large point inputs. Under these circumstances the mass balance model can operate successfully. For basins in which diffuse sources predominate it may be necessary to adopt a different modelling procedure to maintain the advantages of the Trent model. Mass balances are generally not calculable because of lack of information on volumes of water from such sources as field drainage and groundwater seepage. Furthermore, the controls on concentrations of particular solutes are complex. Agricultural basins provide conditions under which point sources are of less importance than diffuse sources. The Trent model applies to highly urbanised watersheds and would be of little use in a rural basin when Nitrate Nitrogen is considered.

Physical models of runoff are being developed which are based on spatially distributed soil parameters (Kirkby, 1975). The possibility exists of these being extended to include solution effects but, physically based models of leaching have not yet been applied to runoff models at any but the smallest scale (Hewlett, 1975). Leaching of Nitrates involves complex chemical reactions and although Gardner (1965) has developed a predictive model for leaching of Nitrates, it is not yet possible to apply it except to laboratory experiments.

Physical laws are known which describe the behaviour of water with reasonable certainty under particular conditions but for hydrological phenomena the scale and complexity of natural systems often prevents their use. Even with the aid of digital computers it is first necessary to consider predictive modelling with the use of purely empiral relations and stochastic simulation techniques. Nash and Sutcliffe (1972) describe this problem for modelling of stream flow and their arguments can be extended to water quality.

The effects of a single point source on river water quality can often be predicted using equations of flow for instance. Where a set of sources are arranged throughout a basin and are operating irregularly the uncertainty in the flow equations, even assuming that volumes and patterns of inputs were known, would preclude a deterministic model of behaviour.

In a rural watershed the majority of water and hence, it is assumed, at least a significant proportion of dissolved load of a river moves from natural drainage systems in the soil and rock and from artificial field drainage systems. Gardner (1968) presents equations describing movement of Nitrogen in soils. His models describe the effects of diffusion and convection of solutes in soil water and the effects of reactions with soil material. He also considers the problem of leaching. Gardner states that considerable uncertainty exists in the use of these equations. The distance Nitrates move down and out of the soil depends on the amount of water passing through, not on the amount of rainfall. The former is extremely difficult to measure. It is also necessary to consider the distribution of Nitrogen in the soil and the soil moisture status before precipitation. Models such as Gardner's are not applicable where boundary conditions are unknown and hydrological properties are extremely variable over short distances. Such are normally the conditions in reality.

Hydrological runoff models using the crudest physical soil parameters have still not been successfully developed (Nash and Sutcliff, 1972; Kirkby, 1975). The application of models based on soil parameters to predict water chemistry has not been attempted beyond the type of study illustrated by Gardner and it is unlikely that his approach will be extended to river basins even if suitable models of leaching can be developed. The application of such models to drainage basins would involve an enormous number of parameters but it is considered (Kirkby,

1975) that a workable model should have no more than five to ten parameters.

Therefore it appears at present that any successful model at the basin scale must be based on statistical relations between Nitrate Nitrogen concentration and some other variables, or on the statistical structure of series of concentration values.

Natural hydrological systems are so complex that no exact laws have been discovered that can describe completely and precisely hydrological phenomena. Systems can be approximated essentially by simulation in various degrees of complexity from deterministic to probabilistic, to stochastic. Because of the uncertainty involved in hydrological system behaviour the most suitable simulation is probably by a stochastic model, in which the behaviour of the system and the processes which take place in it are considered to vary with a sequential time function of the probability of occurrence. In such a model the hydrological phenomenon changes with time in accordance with the laws of probability as well as with the sequential relationships between its occurrence.

The recent developments in stochastic simulation in hydrology have had limited application to problems of water quality. Thornes and Clarke (1975) in a review of work on such problems which use stochastic modelling techniques cite only that by Tomann (1970) which could be used to predict water quality variables on the basis of processes operating in a basin. Edwards and Thornes (1973) have also attempted to reveal underlying causal mechanisms in water quality relations but they have no satisfactory physical model (Dowling, 1974). Most work has been concerned simply with the statistical properties of data series.

Predictions of water quality variables are generally based on statistical relationships with discharge, employing various, simple mathematical models. Successes have been reported with such models but the actual relations between Nitrate Nitrogen concentrations and discharge vary enormously. In some cases a positive correlation is obtained, in others negative, and in others no correlation at all (Feth, 1966). Walling and Webb (1974) and (1975) have begun to investigate the temporal and spatial changes in water quality in more detail but without attempting predictive statements.

Most predictions are for water quality variables at individual points in rivers. At the simplest level are the studies such as those of Tirabassi (1971), Edwards (1973) and Durum (1953) which employ linear regression techniques and line fitting by the method of least squares. Ledbetter and Gloyana (1964) attempted an improvement by applying log transformations with variable exponents to the usual hyperbolic relations. Hart et al (1964), discussing Ledbetter and Gloy na's paper, suggest that their technique can be further improved by a method of separating flow components such as surface runoff and seepage. Similar models are employed by Steele (1972), Johnson et al (1969) and Hall(1970). Each employs line fitting techniques, and success in specific situations is reported.

There are many models in the use of these techniques (Amorocho and Hart, 1964). Water quality-discharge relations are probably non-linear and in the case of Nitrates many biotic and aboitic factors control supply. Therefore, the short period observations on which many of these studies are based, and which provide data amenable to conventional statistical analysis, are unlikely to be useful generally.

There has been a call for water quality studies to be concerned with entire basins as management problems are rarely related to problems at a point (Sherwani 1971, Ledger, 1972). Methods for predicting water quality variables at more than one point in a river have been developed by Dixon and Hendricks (1970) and Faulkner (1972). Faulkner's study of dissolved oxygen is concerned largely with modelling deoxygenation and reoxygenation rates. Dixon and Hendricks (1970) consider dissolved oxygen, temperature and salinity as three representative water quality parameters. Using coupled Fourier functions they model these through space and time for a river network. Both studies encountered the problems of lack of data for large river networks.

In using the approach of linear regression against independent variables there are two principal problems. The first is selecting independent variables which describe the basin characteristics comprehensively and which are available at little cost. The main reason which precludes the use of physically based models is the enormous amount of data which would be needed to describe even a basin of modest size, but in using regression the problem is one of chosing suitable variables.

The obvious types of information to use for basins in rural areas are those which already exist, such as large scale surveys of soil type, vegetation, land-use and geology, and hydrometric information.

The second and more important problem, is establishing the validity of the independent variables in terms of a theory of Nitrate supply to rivers. Studies already exist of the regression of values of Nitrate concentrations in river water against percentage area of various land uses in basins. (Haith, 1976; Shannon and Brezonik, 1972) which assume that the structure of the regression model and the value of the calibrated coefficients have a physical reality. However, the basic premise of this thesis is that to use a regression model for prediction and management it is first necessary to test the validity of the independent variables and the coefficients against an established theory. A second purpose of this thesis is to develop and test such a theory prior to developing a regression model.

Kohnke in 1941 described runoff chemistry as an undeveloped branch of soil science. It is undoubtedly true that this is so at the present time. In recent years there have been significant advances in the development of hydrological models. Hydrologists have been concerned almost exclusively with predicting stream flow and developing suitable physical or operational models. Relatively little attention has been paid to problems of water quality.

Nash and Sutcliff (1972) advocate, at the present state in the development of hydrological prediction, the design of empirical runoff models which are based on soil parameters. They regard the use of stochastic techniques as an important part of design with the incorporation of more deterministic elements when the sensitivity and reliability of empirical models have been tested. Similar developments are required in the modelling of runoff chemistry. The point is that at present in water quality studies a reliable theory needs to be established and an empirical statistical model needs to be tested before more physically based models can be developed. What follows is an attempt to develop a predictive statistical model for Nitrate Nitrogen concentrations in a river draining a rural watershed (that of the River Rother in West Sussex and eastern Hampshire, England) which is based on a physical theory, and which may eventually be used with a runoff model to produce one of water quality.

The choice of Nitrate Nitrogen is justified in Part 2 which is a general treatment of the role of Nitrogen in water. The processes which operate within the Rother basin to control Nitrate Nitrogen concentrations in the river are considered as a sub-set of all the processes which could affect Nitrogen in the environment. Therefore, the basin is described in general terms in Part 3 and then an assessment is made in Part 4 of the behaviour of the types of source of Nitrate Nitrogen which are found in the study area. Part 4 ends with a set of general hypotheses about the concentrations of Nitrate Nitrogen to be found in the Rother basin. In Part 5 the independent variables in a regression model are chosen and, on the basis of Parts 2, 3 and 4, a set of specific hypotheses are made about their relation to Nitrate Nitrogen concentrations.

In Part 6 the methods of obtaining data are described. The hypotheses are tested in Part 7 using a set of controlled observations of springs and field drains. In rivers Nitrate Nitrogen concentrations are affected also by sewage and the behaviour of sewage works is described in part 8, before rivers are considered. In Part 9 the hypotheses are re-examined against observations of Nitrate Nitrogen in rivers which represent the effects of uncontrolled variables. The relations between the observations and the independent parameters are expressed by means of a regression model. Parts 10 and 11 consist of attempts at a predictive model based on the relations of Part 9.

PART 2

NITROGEN AND ITS COMPOUNDS IN THE ENVIRONMENT.

CHEMISTRY OF NITROGEN

Nitrogen appears in nature in the form of a chemical compound or as a diatomatic molecule. There is a Nitrogen Cycle whereby a more or less steady state is set up for chemical transformations between the inorganic Nitrate, Nitrite and Ammonium ions and a number of organic compounds the most important of which are the proteins. The transformations are largely by biological agents. Molecular Nitrogen dissolved from the atmosphere can be converted to organic compounds by certain Nitrogen fixing bacteria and algae. Most plants use Nitrogen compounds. In rivers and lakes these are derived from various sources such as land runoff and effluents. In addition Ammonia is released by decomposition of organic materials and this may be used by plants for re-synthesis back to organic Nitrogen. The Ammonia may also be oxidised to Nitrites and Nitrates by organisms which use the reaction as an energy source under aerobic conditions. Under anaerobic conditions Nitrates may be reduced by heterotrophic bacteria to Nitrites and N_2 gas (Figs 2i and 2ii)

Nitrogen gas has a solubility in water of about 15 mg/l at 20^{o}C. This concentration is higher than that normally found for other Nitrogen species. However molecular Nitrogen is very stable and can be considered chemically inert. It is generally of little direct biological importance.

Reduction of Nitrogen to organic Nitrogen incorporated into cells takes place under the influence of certain bacteria, notably Azotobacter

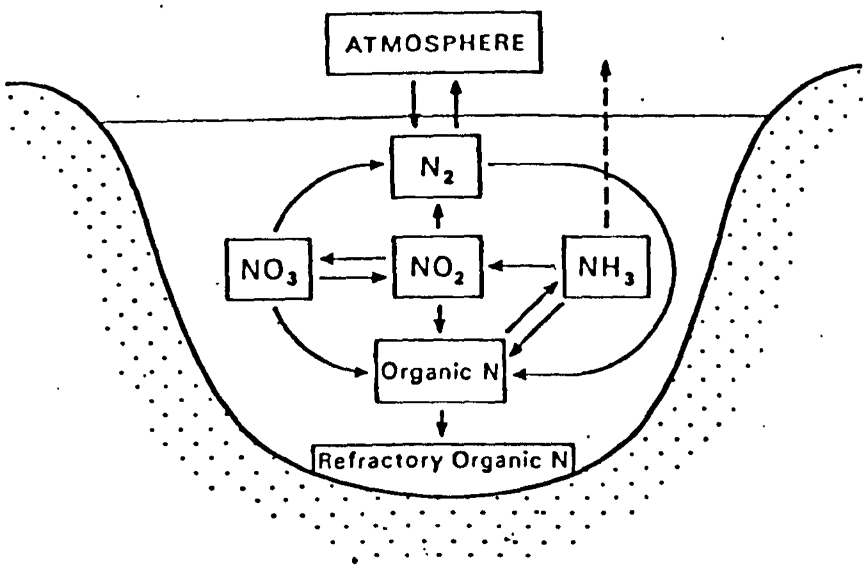


Fig. 2i

Transformations of Nitrogen in Water

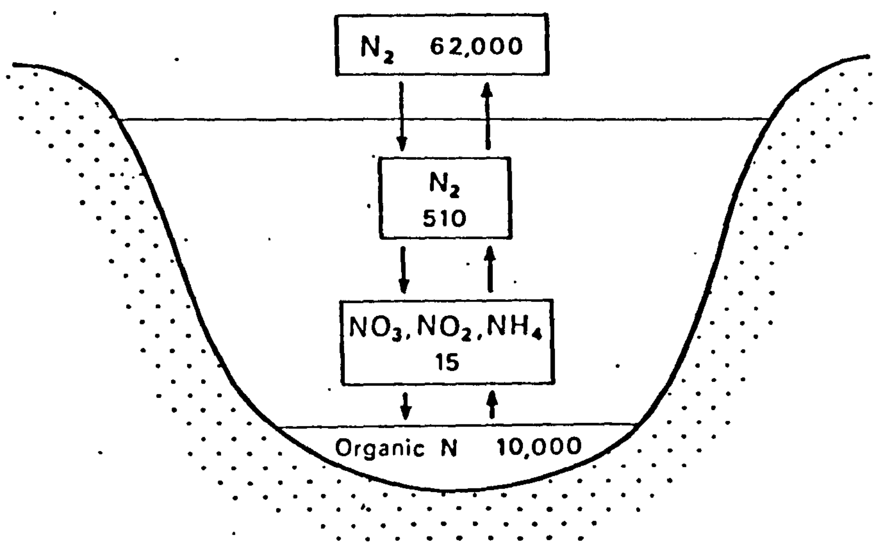


Fig. 2ii

Atom equivalents of Nitrogen in Water Bodies.

and Chloridium species, autotrophic bacteria, various phytosynthetic bacteria and a number of blue-green algae. The process is very slow and Dugdale and Dugdale (1962) show that under natural conditions in lakes a period of seventy days would be required to double the supply of Nitrogen. In running water the same effect would be observed only if the rate of flow were such that the residence time for the algae in the water were at least this long.

Ammonia is very soluble in water and acts as a weak base. It takes part in many reactions and exhibits significant sorbtion properties. Complexes with metal ions can be formed but in natural waters the effect is small. The Ammonium ion exhibits a strong tendency to replace monovalent cations in exchange reactions. It can also become fixed within the lattices of clay minerals and remains relatively inert in this state.

In natural conditions of surface water, with near neutral pH, Ammonium Nitrogen is converted to other forms mainly through biological action. It may be incorporated into the organic Nitrogen fraction of autotrophic and heterotrophic organisms or it may be oxidised to Nitrite bacteriologically. Oxidation in rivers and most lakes generally goes to completion with the formation of Nitrates.

Nitrite Nitrogen is rather unstable and is readily reduced or oxidised. Nitrites can be reduced in water by Sulphides or Ferrous ions. The major routes of conversion at the neutral pH of most surface waters are biological oxidation to Nitrates under aerobic conditions or reduction to N_2 under anaerobic conditions.

Nitrates are very soluble in water. No poorly soluble salts exist and they are not readily absorbed. In addition they are relatively non reactive under the conditions found in natural waters. The major factor influencing their transition is biological action including incorporation into organic matter by both autotrophic and heterotrophic organisms.

Organic Nitrogen is formed and degraded primarily by biological action. The commonly recognised forms of organic Nitrogen are proteins and protein derivatives, purines and pyrimidines and urea. Nitrogen in urea is highly available biologically but much organic Nitrogen is considered refractory, being released extremely slowly.

Fig. 2ii shows the steady state conditions thought to exist in a typical body of water with respect to Nitrogen (AWWA Committee Report, 1970). Few studies of nutrient cycling in running water have been carried out (Haynes 1970) and although the transformations are by the same mechanisms it is not yet possible to give a comparable estimate for rivers. The situation in rivers should not be very different from small lakes except that aerobic conditions will prevail. In addition sediments will be disturbed a great deal more and therefore tend to release more Nitrogen, so that this store may be more active in river environments.

Fruh (1968) in his review of nutrients in freshwater points out that in eutrophication studies many conclusions cannot be accepted at face value because Nitrogen determinations were limited to the Nitrate concentrations in the water. However, in rivers which are not very badly polluted, the Ammonium and Nitrite species are quickly oxidised and the majority of dissolved Nitrogen, apart from the gas, will be in the Nitrate form.

It is highly likely that a river will remain saturated with respect to molecular Nitrogen throughout its length as there is a constant turn over of water. However, the critical species for the movement of Nitrogen in a river like the Rother, is Nitrate. Therefore, attention has been confined to Nitrates.

THE ROLE OF NITROGEN IN WATER

Particular stress has been laid on the influence of Nitrates on phytoplankton growth because of their limiting supply. Conditions which govern the growth of organisms are extremely complex. Phytoplankton are influenced by the available sunlight and other physical factors such as turbulence and temperature. There are chemical factors controlling growth such as the supply of other nutrients and the presence of toxins. In addition there are biological factors due to the influence of one organism on the growth of others. Nutrient factors are emphasised, not because the importance of the others is underestimated but, because they are for all practical purposes beyond control. Moreover, in a great many situations the other factors remain constant and changing ecological parameters are directly related to changing nutrient supply.

Viets (1961) argues, for higher plants, that on the basis of the relative number of atoms needed for growth, Nitrogen is at the top of the list of those that come from soil or fertilisers (Fig. 2iii). In lakes and rivers Hydrogen, Carbon and Oxygen are in good supply and Nitrogen is the main element, along with Phosphorus, which is most likely to be in limiting supply in neutral waters (Hutchinson 1957, Fruh 1967, 1968, Gerloff and Skoog 1937, Sawyer 1962, Chu 1943, Juday and Schloeman 1938, for example). This study is concerned only with Nitrogen.

Knowledge of the effects of nutrients is still so poor that numbers and types of algae or higher plants which will develop under given conditions cannot be predicted (AWWA Committee Report 1966). Sawyer (1947) gives a specific concentration of inorganic Nitrogen for lakes in South East Wisconsin, above which nuisance conditions can be expected (0.3 mg/l.). However, it is clear that specific limits cannot be given. Total or "available" Nitrogen is rarely measured and some algae can fix gaseous Nitrogen and obtain it from bacteria (Fruh 1968)

Many examples exist which show clearly the effects of eutrophication particularly by sewage effluents. Minder's (1943) study of Zürichsee illustrates that Nitrogen from sewage effluents has caused seasonal blooms of algae, principally of the blue-green variety. Hasler (1947) lists thirty seven lakes in Europe and the United States which have changed from being oligotrophic to

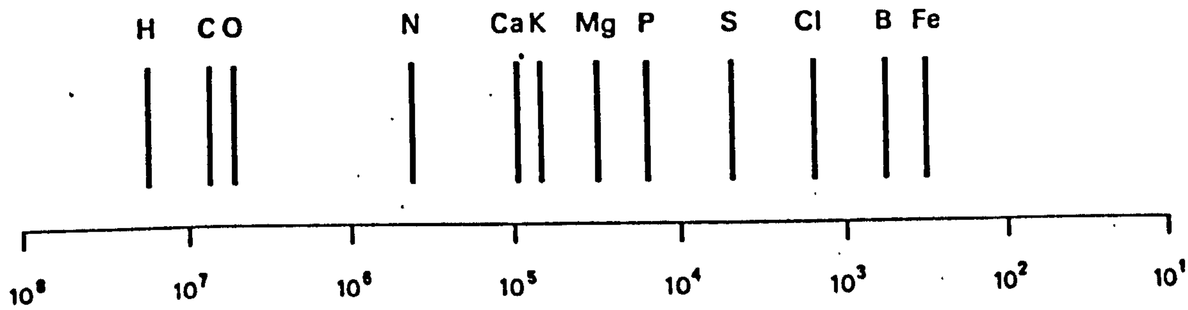


Fig 2iii

The relative number of atoms in the essential elements of Alfalfa

at bloom stage (log scale),

after Viets, 1961.

eutrophic during the last century, generally under the influence of sewage effluents. This is an increasing problem because of the growth of population and the changing techniques and demands of agricultural practices.

Rivers present a much more subtle ecological problem and very little work has been done on algae in running water. Where rivers flow through areas rich in Nitrates algal growth increases (Oliff et. al. 1955). The abundance of filamentous algae below sewage outfalls is well recorded. Butcher (1932, 1947) showed that algal communities above sewage outfalls were dominated by Locconeis spp. and Ulvella spp. whil e downstream Cromphonema, Nitzchua and Stigeoclonium become dominant. Zimmerman's (1961, 1962) experiments on artificial channels, although primarily on the effects of current velocity do show the importance of water quality on algal community structure in running water.

Haynes (1970) considers that plants take up Nitrates in streams and maintain low concentrations. This is dubious simply because Nitrate levels recorded in streams and rivers are rarely low except where they drain areas of natural vegetation. Very little is known about the influence of nutrients on higher plants in rivers but it is well established that channels very rich in plants can reduce the dissolved Nitrate content of the water passing through them. Rivers constitute a nutrient rich environment because running water prevents the accumulation of shells of depleted water around organisms. Odum (1956) considers that polluted streams are the areas of highest primary production on the planet for this reason. But, in rivers generally algal blooms or the growth of large stands of higher plants are not recorded because of the unstable nature of the environment. Only in small channels under low flow conditions are relatively large masses of vegetation observed. Few studies of rivers in England have mentioned the role of plants in utilising Nitrogen. Owens' (1970) study of the River Great Ouse shows a discrepancy between observed nitrogen load and that estimated. He attributes this to possible uptake by plants. However, his information is not nearly precise enough to do this.

NUTRIENT ASSOCIATED PROBLEMS

The major problems caused by Nitrogen in its role as nutrient is through influencing the growth of phytoplankton in lakes. Eutrophication generally results in increased primary production and in the most severe cases "blooms" of algae. When such large masses of algae die and decompose they impose a great demand on the oxygen content of the water. Such demands can severely affect fish populations and produce foul odours. Gorham (1961) reports that toxins produced by blue-green algae had harmful effects on humans. Some evidence (Tisdale 1931, Veldee 1931, Dillenberg and Dehnel 1960) indicates a relation between algae and gastroenteritis but the relation is not proven and ill effects may be due to associated bacteria. In some human beings bacteria can produce Nitrosamines, which are carcinogens, from Nitrates. Evidence has been presented that where the water supply contains abnormally high Nitrate content (20-25 mg/l, NO_3-N) the death rate from gastric cancer is also high (Hill et. al. 1973).

A problem of great importance is the effect of algae on Water Treatment Plants. Large numbers of aquatic plants may affect colour and turbidity, but these effects are eliminated by filtration. However, decomposition products are often highly coloured and produce offensive tastes and odours. "The blue-green algae are notorious for their pig-pen odours in water supplies" (AWWA Committee Report 1966).

One of the most common problems associated with algae is the clogging of filters. Palmer (1962) reports that in extreme cases the water required to backwash filters is greater than the amount of filtered water.

The effects of algae on recreational facilities in lakes are receiving greater attention. Apart from the effects on fishing, other higher animals, invertebrates and plants can be affected so that the whole lake environment changes. Boating and swimming facilities may be affected by development of littoral weed and filamentous algae.

The role of phytoplankton in rivers has been less explored than that of rooted plants (Downing 1968). Their presence is unlikely to present problems of severe deoxygenation in rivers to the same extent as rooted plants and only in very densely vegetated stretches of channel will higher plants cause such conditions. Hynes (1960) points out that the density of vegetation in rivers is much smaller than on land and is often grossly overestimated.

A further problem associated with Nitrates in drinking water, which has received much publicity is that of cyanosis (blue babies) in infants fed with water having a moderately high concentration. Nitrate is converted into Nitrite in the infant stomach, which in the circulation oxidises the ferrous form of haemoglobin to ferric, with the production of methaemoglobin Comley (1945) The USPHS drinking water standard is 10 mg/l NO_3-N. Few cases of cynosis have been reported from public water supplies but where there are small private extractions from ground water it can present a problem. In the United States there are many such abstractions and George and Hastings (1951) report twenty seven public supplies in Texas regularly containing over 50ppm of Nitrate (= 12mg/l NO_3-N) and because of such supplies Several deaths have been reported in the United States recently. Occasional high levels of Nitrate are reported in Britain where public supplies are from ground water (Green and Walker 1970)but no deaths. It is worth mentioning that the effect of Nitrates is difficult to diagnose.

PART 3

STUDY AREA

The area studied is the basin of the River Rother in West Sussex and eastern Hampshire above Iping Weir, where the Sussex River Authority operate a flow gauging station (Fig 3ii). The basin is 153.6 sq. Km. in area.

GEOLOGY

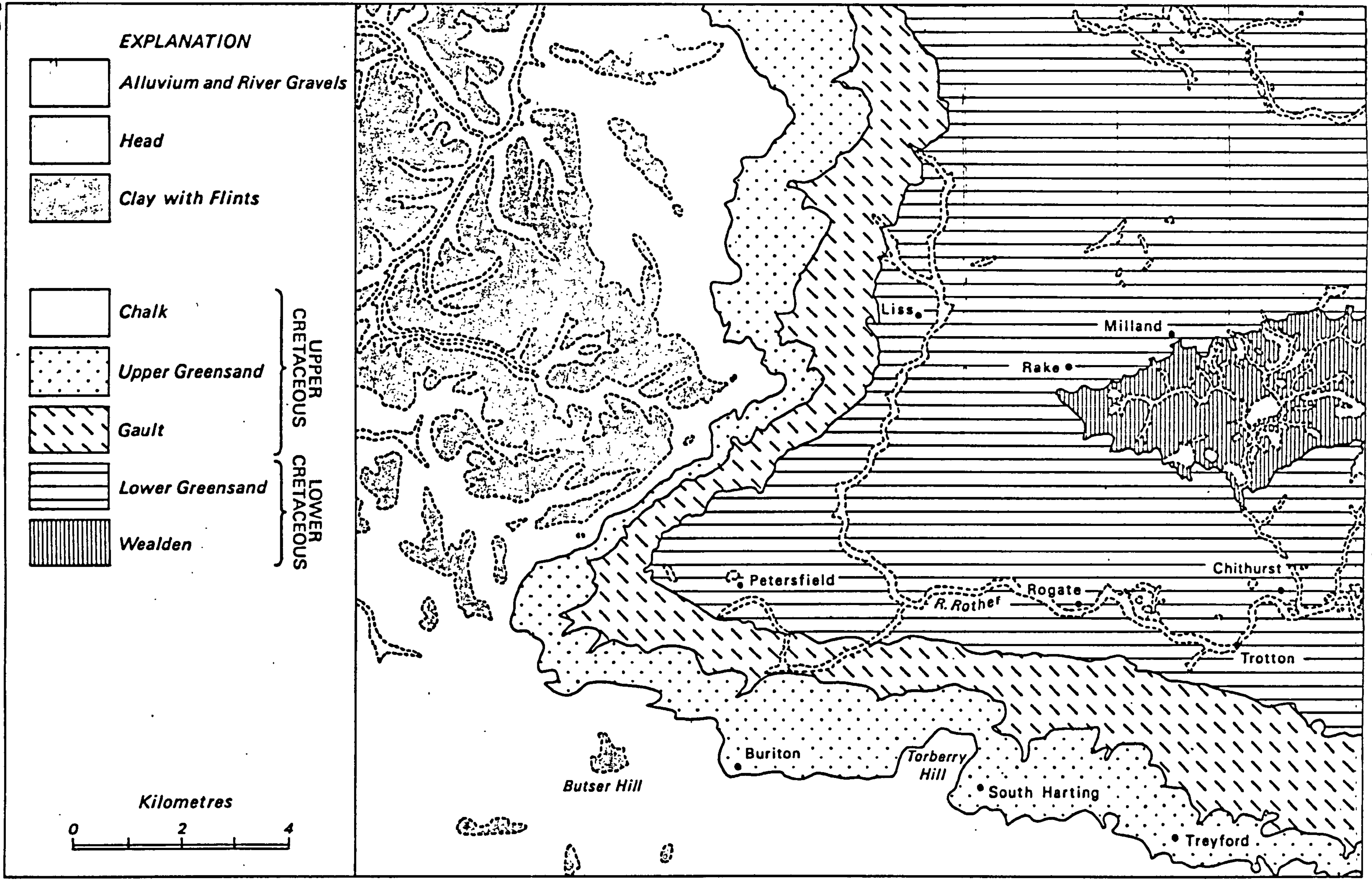
Of fundamental importance in understanding the geography of the area are the geological structure and lithology. Topography, hydrology, soil, land use and settlement are each intimately related to geology and thus a systematic description of the area is necessary in order to put this study of Nitrates into a regional context.

Only Cretaceous and recent rocks are represented in the area. They are, with their approximate thicknesses, as follows (based on British Regional Geology, The Wealden District (Fourth edition), 1965).

CHALK	up to 400 m.
UPPER GREENSAND	30 to 40 m.
GAULT	up to 60 m.
LOWER GREENSAND	
Folkestone Beds	50 to 90 m.
Sandgate Beds	15 to 50 m.
Hythe Beds	0 to 40 m.
Atherfield Clay	10 to 20 m.
WEALD CLAY	up to 500 m.

The Wealden anticlinorium dominates the overall geological structure with flexures, arranged en echelon, being important locally (Fig, 3 i)

Fig. 3i Geology of the Western Weald.


EXPLANATION
Alluvium and River Gravels
Head
Clay with Flints
Chalk
Upper Greensand
Gault
UPPER CRETACEOUS
Lower Greensand
Wealden
LOWER CRETACEOUS
Kilometres
0
2
4
Liss
Milland
Rake
Petersfield
Rogate
R. Rother
Chithurst
Trotton
Buriton
Torberry Hill
South Harting
Treyford
Butser Hill

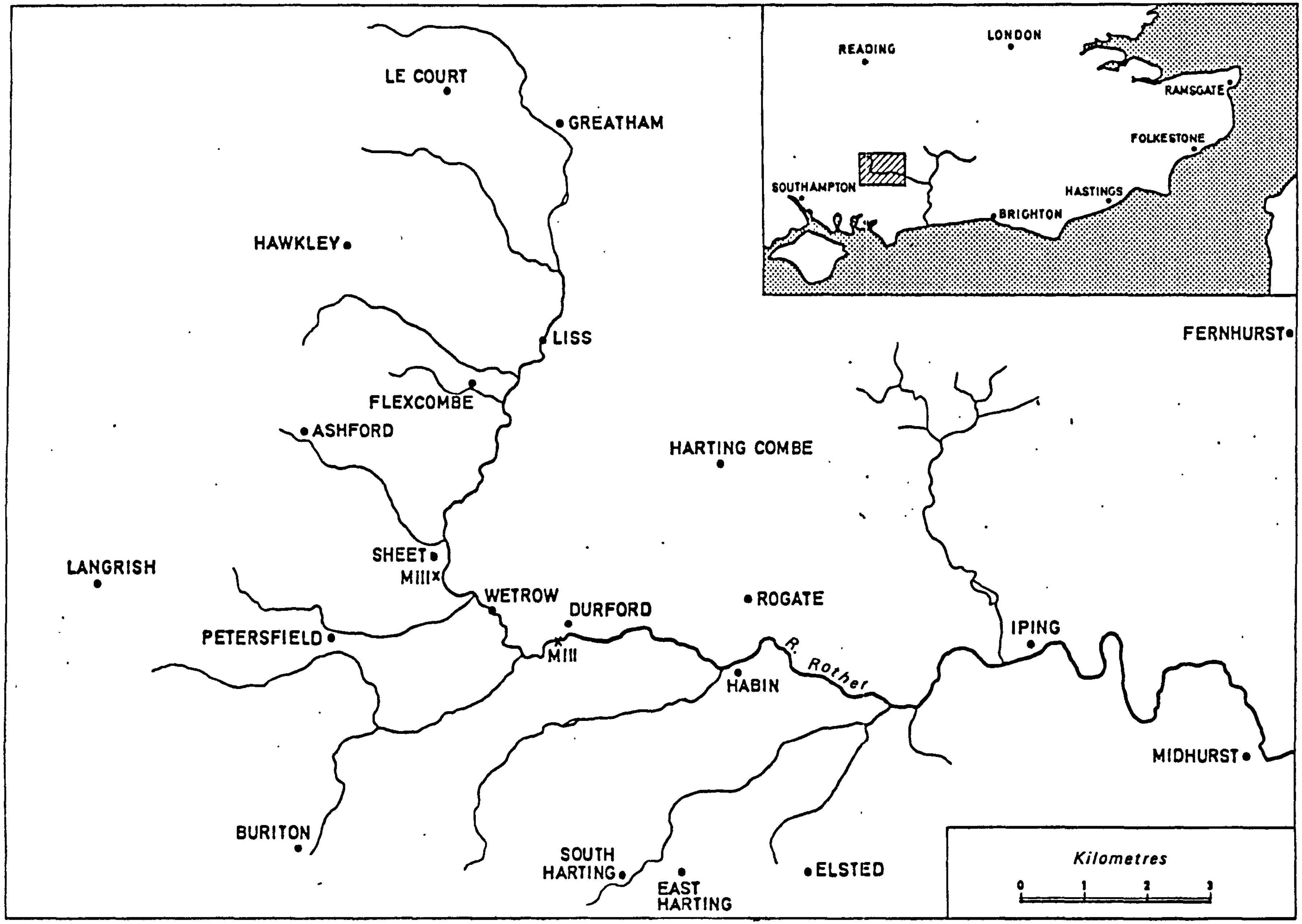


Fig.3.ii Location Map of Places Mentioned in the Text.

They produce significant westerly extensions of the Weald Clay outcrop and south westerly bulges of the outcrops of the Lower Greensand, Gault Clay and Upper Greensand. There are no important faults in the area.

The rocks of the area are principally sandstones, clays and chalk. Weald Clay, the lowest member of the Cretaceous series represented, outcrops in the centre of the Fernhurst and Harting Coombe anticlines (Fig. 3ii). It consists of siltstones and mudstones with subordinate sandstones, limestones and clay ironstones.

The Lower Greensand is predominantly arenaceous but subsidiary amounts of silt and clay are present. Chalk, ironstone, and calcareous material also occur. There are four main lithological divisions, Atherfield Clay, Hythe Beds, Sandgate Beds and Folkestone Beds which exhibit considerable variability within themselves. The Atherfield Clay consists of shales and mudstones which weather to brown mottled clays.

The Hythe Beds consist of fine grained glauconitic sand and sandstone. The lower part forms a transition to Atherfield Clay which contains considerable silt and clay. In the upper parts the sands are hardened to beds of compact non-calcareous sandstones with subordinate lenticular beds of chert.

The Sandgate Beds are ferruginous clayey sands. They exhibit considerable variability. In the study area the Bargate Beds are well developed and these are characterised by lenses of pebbly calcareous sandstone. The top of the sandstone beds between Petersfield and Midhurst, the Pulborough sand rock, is a silty micaceous sandstone. The highest member is the grey shales, the Mareshill Clay.

The Folkestone Beds consist of predominantly coarse grained, poorly consolidated sands with seams of pebbles and clay. Veins and doggers of hard ferruginous sandstone are found.

The Gault is the lowest member of the Upper Cretaceous Series. With the Upper Greensand it forms part of a single sequence which is at its thickest in this area. The term Gault is applied to the more argillaceous facies and Upper Greensand to the arenaceous. A few feet of silts and sands are commonly found at the base of the Gault which generally consists of dark, bluish-grey clays and silty mudstones with occasional bands of phosphatic nodules.

The Upper Greensand shows great lithological variability over the study area. Poorly consolidated siltstones occupy the lowest part of the formation in transition from the Gault. Overlying these are predominantly sandy beds which contain small amounts of silt and clay. The top of the Upper Greensand in places consists of a clayey sandstone with glauconite grains, in other places a quite impermeable hard "blue" rock.

Chalk is a soft, white, friable limestone consisting of 95% calcium carbonate. There are three main divisions, Lower, Middle and Upper, which exhibit great lateral uniformity. In the Lower Chalk a considerable amount of argillaceous and arenaceous material is present, particularly in the lowest beds. Upwards the Chalk becomes purer gradually and more thickly bedded and hard bands are formed.

The Middle Chalk is also a pure, massive rock with a hard, yellowish streaky marl layer at the base, the Melbourne Rock. In the top thirty feet flints and beds of nodular chalk also occur. The bulk of the Upper Chalk consists of soft, white rock with flints and with beds of hard, nodular chalk near the base.

Superficial deposits are widespread but rarely thick. Head deposits are confined to the Hammer Catchment (Fig. 3i). These rubbly beds are principally a mixture of debris from the Hythe Beds and Weald Clay Sandstones. They extend from the Hythe Beds escarpment over the lower clay areas.

River terrace gravels are very restricted. Four terraces have been attributed to the Rother and others to its larger tributaries, There is no well developed flood plain but complex mixtures of sands, clays and gravels have been observed.

TOPOGRAPHY

There is a marked relation between geology and topography. The area is one of scarp and dip slopes being dominated by the Chalk and Hythe Beds escarpments. Their locations are determined by the Wealden and the smaller antidines. The Chalk escarpment runs north north east and east from Langrish enclosing the Rother basin. It varies considerably in height from 150 to 250 meters but is everywhere a dominant feature of the landscape. At its base and running parallel to it is the Upper Greensand bench. This has a marked slope in the direction of dip but where it is wider, especially between Buriton and Elsted, it is almost level over extensive areas. It too has a steep though small scarp slope parallel to the Chalk which overlooks the low lying Gault land. This is an area of low relief and gentle slopes which merges unnoticeably topographically with the Lower Greensand. The topographic relation with geology is hardly broken by the presence of the Rother which flows with the grain of the country along the Lower Greensand.

On the right side of the Rother the Folkestone Beds often form higher areas, covered with heath, between the various tributaries flowing off the Gault. Small discontinuous inward facing escarpments are often found on the Folkestone Beds. There is little area of flood plain and the river is often overlooked by steep slopes in Folkestone Beds.

The land rises gradually to the crest of the Hythe Beds escarpment. This is the second major topographic feature of the area. It extends in arcs eastwards from Harting Coombe and encloses the lower lying ground in the centre of the anticline occupied by the Weald Clay. Like the Gault lands, this is an area of low relief and low angle which extends eastwards towards the centre of the Weald beyond the study area.

HYDROLOGY

There is a close correspondence between lithology and surface and subsurface hydrology which emphasises the landscape divisions based on topography.

The Chalk is devoid of surface drainage. Along the base of the scarp are several large springs. They are associated with joint and fissure systems and probably receive water from an area stretching well beyond the surface basin. A strong flow is maintained throughout most of the year; only during late summer is there any serious reduction.

There are many smaller temporary springs at the foot of the scarp many of which join drainage off the Upper Greensand flowing parallel to the scarp.

The Upper Greensand is a second permeable rock from which many springs are fed. Some rise on the low lying parts of the formation near the base of the Chalk escarpment. Many are found at the junction with the Gault (Fig. 3i). There are also a series of small gorges, or crundles, eroded into the Greensand scarp which intercept the water table in winter. Perched water tables are a common feature of Upper Greensand and can support substantial flows for much of the year.

The heavy clay lands of the Gault are relatively impermeable. Many streams and artificial channels drain the area. Streams headed in Upper Greensand or Chalk springs gain many tributaries in passing over the Gault (Fig. 3i).

The Lower Greensand, being a very permeable rock is also devoid of surface drainage. Springs emerge at the junction of the formation with the Gault, Weald Clay and river alluvium. Most of the Lower Greensand drainage emerges as springs close to the Rother. Many enter the river through the banks and bed. There are no springs as large as the major Chalk springs but they are certainly more numerous. Drainage to the Hammer Basin is generally very complex. Slipped material over Atherfield and Weald Clays masks many sites and the term "seepage line" is more fittingly applied to springs at the base of the Hythe Beds escarpment.

The sandstone beds of the Weald Clay series support small springs. These beds have a very irregular distribution (Fig. 3i) and the Weald Clay series can be considered to contribute ground water throughout its entire area. There is a dense surface drainage network which has an outlet to the Rother through a gorge in the Hythe Beds (Fig. 3ii).

The average annual rainfall is between 850 and 1000 mm. being heaviest on the Chalk downs and diminishing towards the north east. At Rogate near the centre of the basin the rainfall is 873 mm. During the period of study there were large departures from these long term averages. At Rogate, for instance, the 1972 total was 869mm., whereas for 1973 it was 583mm. Over the study period the rainfall totalled 732mm. There were only two months with moderately heavy precipitation, the rest were below normal. The monthly totals in mm. are:

1972											1973
O	N	D	J	F	M	A	M	J	J	A	S
31.8	98.5	144.2	41.6	25.1	24.5	60.0	73.1	51.1	73.1	30.3	78.7

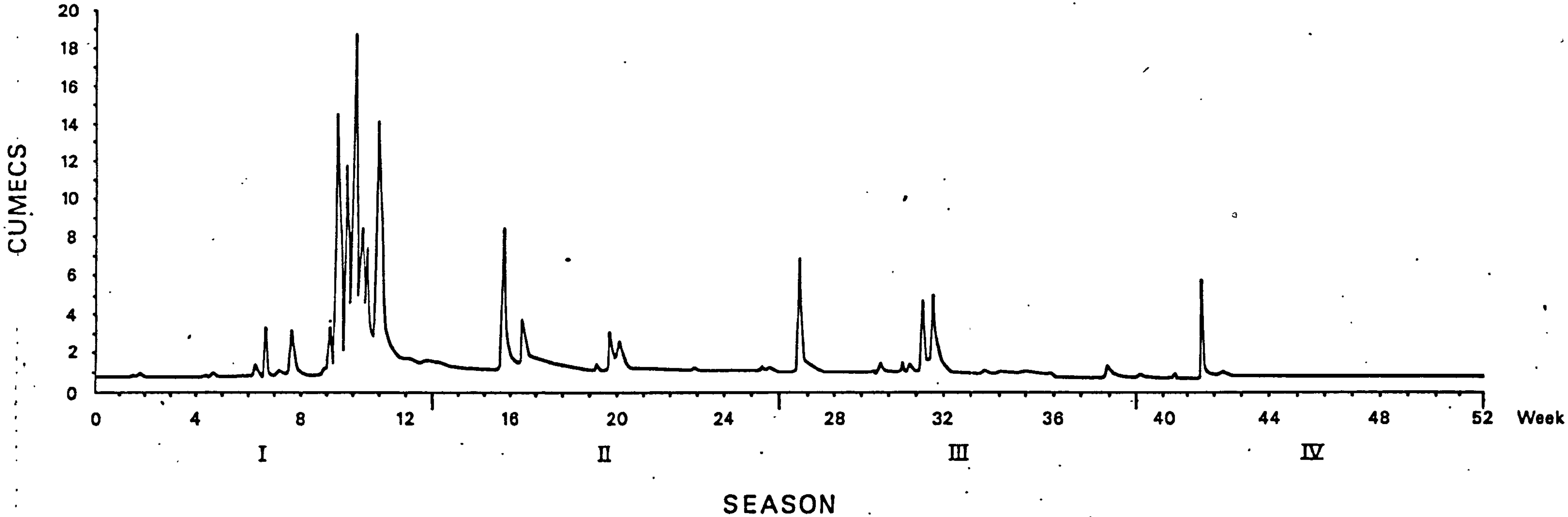


Fig. 3iii

Hydrograph at Iping Mill - 1972/3

It is difficult to give a description of characteristic hydrological conditions at any particular time of year. However, it is usual for winter flows to be much higher than summer and most springs and land drains run continuously. Only towards the end of summer do larger springs from the Chalk and Lower Greensand begin to dry up.

During 1972-73 there were no more than five or six weeks when the entire sample of drains flowed and by May 1973 many springs which had been observed flowing in late summer of 1972 (not a wet year) were dry. River flow during January, February and March was at summer levels. The dryness of the year is illustrated by the effect of heavy rainfall on runoff. On July 12th, 1973 a rainfall of 56 mm was recorded at Rogate (Fig. 3ii) in a ten hour period. Most of the sampled drains [redacted] were not seen to flow at this time. [redacted]. No other rain events during the period from late March to August 1973 had any observable effect on spring or drain flow at study sites.

SOILS

Soil type is closely related to parent material, topography and hydrological conditions and although great variations in soil properties exist the basic soil types in the area can be described on the basis of the principal geological divisions.

The Chalk supports a thin, highly organic, Rendzina type soil, for the most part with high pH. Many chalk particles and flints are generally found. During the Second World War large areas of downland were ploughed and this continues. At these sites the soil is very thin. Thicker, less basic soils are found on low angle slopes and under woodland, particularly at the base of the escarpment. Deep Chalk soils are not represented in the basin.

The Upper Greensand has been cultivated intensively for centuries and no natural soil types can be distinguished. Agriculturally it provides a heavy loam soil excellent for arable cultivation. There is little acidity. There is a high proportion of silts and clays in the soil and although they tend to be sticky in winter and hard in summer they are generally well drained.

The Gault and Weald Clay soils are similar in texture and general condition. Being heavy clays their drainage is poor and anaerobic conditions are usual. They have a low calcium content which adds to the difficulty of their use. In winter they are wet and heavy, in summer hard and dry. On the parts of the Weald Clay where sandstones and limestones are exposed there are local improvements in texture and drainage.

The Folkestone Beds produce a poor sandy soil susceptible to strong leaching. There is often a cover of flint debris associated with river terrace deposits which makes the soils very stoney. On the common lands south of the Rother well developed podzol soils have formed under heathland.

A light loam soil is found on the Sandgate Beds. These beds having a good silt and clay content provide a good agricultural soil which is intensively cultivated. Some parts of the Sandgate Beds which are very sandy, have soils little different from the Folkestone Beds.

Hythe Beds Soils are similar to the Folkestone Beds and being generally at a higher elevation suffer from exposure. Under heath and forest a podzol is usual. The lower lying (uppermost geologically) parts provide soils intermediate in character with the Sandgate and agricultural land extends to the higher parts of the Hythe Beds.

LAND USE

Land Use, a most important factor in Nitrate supply is closely related to soil type and geology. The land uses on the different geological divisions are presented as percentages of their areas (Fig. 3 iv). They were mapped in the field during the summer of 1973.

The Chalk within the defined basin is mostly escarpment. This supports a cover largely of woodland, rough grassland and permanent pasture. Arable land extends over the lower part of the outcrop from the Upper Greensand. The Higher parts of the Chalk are almost entirely in permanent pasture. On lower lying areas beyond the basin much arable land is found. Barley is the main crop and Nitrogenous Fertiliser applications are moderate (see Appendix 1).

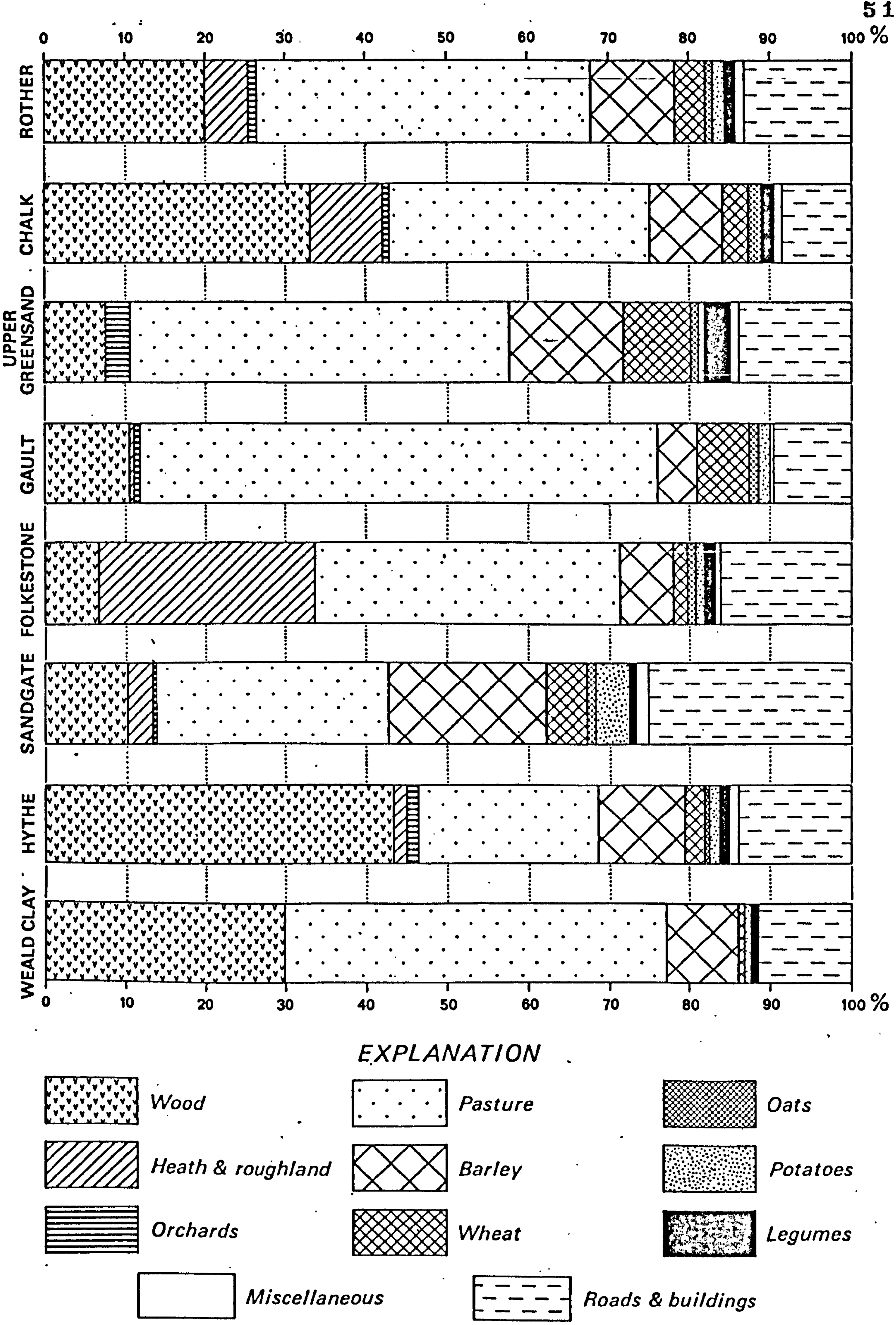


Fig. 3 iva

Percentage area in different land uses on the main geological divisions

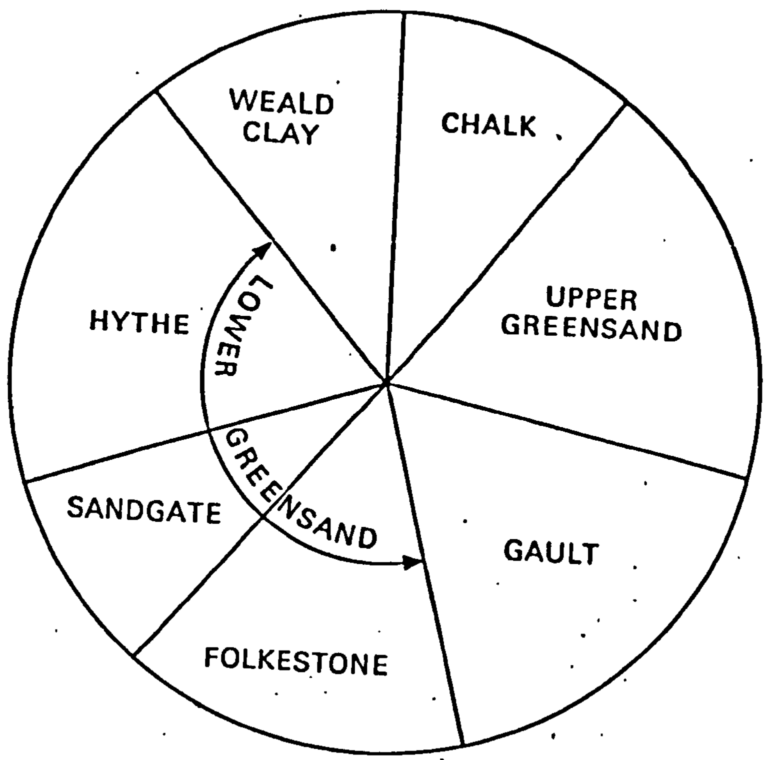


Fig 3 ivb

Proportional contribution of different Geological type to the total area of the Rother Basin.

The Upper Greensand provides one of the two main arable areas of the Rother Basin. Cereals, especially barley, are dominant. Pasture is generally part of a rotation. It is interesting to note that the appearance of predominantly arable farming can be misleading. Over fifty per cent of the formation is under wood and pasture. The Upper Greensand supports a string of large prosperous farms with mixed enterprises. Milk and beef are established at many and pigs are numerous. Stocking rates are high.

Permanent pasture is the dominant land use on the Gault, covering over 60% of the area. Fields may be ploughed and left fallow for a season for improved ley. There is a relatively small area under cereals. Milk and beef herds are the major enterprises of farms on the Gault and stocking rates can be very high. Farms frequently extend over the major geological divisions and where this is the case the enterprises suitable to the particular soil types are found on the proper section of a farm.

A great deal of the Folkestone Beds is under heathland. Much of the remaining land is under permanent pasture. On lower parts, expecially towards the Sandgate Beds a wide variety of crops are grown; predominantly barley.

The second major area of arable land is found on the Sandgate Beds. Intense cultivation extends from the Folkestone Beds to the Lower Hythe Beds, wheat and potatoes and barley are the major crops. As with the Upper

Greensand a large percentage of the area, over 40%, is under wood and pasture. In addition the Sandgate Beds has the largest proportion of its area under roads and settlements.

Large amounts of wood-land characterise the Hythe Beds areas. Arable land use is not unimportant but is generally an extension of arable enterprises on the Sandgate Beds.

Large amounts of wood-land and pasture characterise the Weald Clay lands. Barley is the major crop. Substantial dairy and beef herds are kept at most farms.

EFFLUENTS

The major centres of population are at Liss, Petersfield, Greatham, Rogate, South Harting, Hawkley and Buriton. Five of these centres have sewage works which discharge into the Rother and its tributaries. The Sussex River Authority (1968) gives dry weather discharges of 1963 as follows:-

	M^3/DAY
Petersfield	1980
Liss	1210
South Harting	170
Rogate	115
Buriton	95

A small unit at Le Court serves the community there. It has an average dry weather flow of 25 m^3/day.

Away from the areas served by the sewage system houses and other buildings are served by septic tanks. Some buildings and farms discharge directly to water courses. South Harting works accepts effluent from three farms and Petersfield's largest input is from an abattoir.

PART 4

SOURCES OF NITROGEN

SOURCES OF NITROGEN

Many of the factors which control the levels of Nitrogen in rivers and lakes are changing rapidly. Agricultural practices in England and most other countries of the world have been revolutionised in the past twenty five years. Fertiliser Nitrogen applications have increased tremendously and although they are beginning to level off in England, they are still increasing rapidly elsewhere and in some countries are expected to continue to do so for many years more. Land use practices are changing and it is becoming increasingly common for livestock and other animals to be kept permanently in large intensive units which can potentially provide enormous supplies of Nitrogen. In addition the population is growing and human waste products form a rapidly increasing addition to the Nitrogen load of rivers. Changes in these and a list of other factors raise the question of what effects can be expected on the Nitrogen levels of rivers and therefore of lakes and estuaries.

It is necessary to consider first the different sources of Nitrogen to rivers. Collectively they have received enormous attention in the literature. It is impossible to present a full account of the work done on the behaviour of these various sources but the major aspects need to be considered carefully.

RAINFALL

Nitrogen in rainfall, as an addition to agricultural land, has been measured for over one hundred years. However, surprisingly little is still known about Nitrogen levels in rainwater and where the Nitrogen comes from. There is still much disagreement about the nature, origin and distribution of Nitrogen compounds in precipitation and few conclusive pieces of evidence can be presented.

Only two studies are known which use reliable data, for many stations over large areas. They are those of Angstrom and Hogberg (1952, 1952a) and Junge (1958). Junge (1954) emphasised the abundance of Ammonium bearing particles in atmospheric aerosols. Samples taken near the earth's surface contained large particles which consisted entirely of Sulphate and Ammonia. Giant particles at times consisted entirely of Nitrates (Junge 1954). Junge and Manson (1961) report a stable aerosol layer, virtually world wide in extent, at altitudes between 15 and 25 Km above the earth. There is a constant fallout and replacement of these particles of Ammonium Sulphate and Persulphate. At lower layers they are available for incorporation into rain and snow and many constitute dry fallout.

Junge (1958) conducted a survey of Ammonium and Nitrate ions in rainwater over the United States using data from sixty stations for one year (July 1955 - June 1956). This study showed markedly uneven areal distribution of both ions. Values were low near coastlines and at the far ocean points. Data from northern Europe indicate no difference between coastal and inland areas. Junge concludes that the major sources of fixed Nitrogen were confined to certain geographical areas over land.

No correlation was found with thunderstorm activity, density of industry, population or agricultural activity. However, areas of soil of low pH capable of absorbing Ammonia correlated with areas having low concentrations of Ammonium ions in rainwater and vise versa. Angstrom and Hoberg (1952, 1952 a) report data for Sweden which shows a correlation between Ammonium and Nitrate concentrations and the character of the air mass from which rain fell. Tropical air contained between 10% and 30% greater Nitrogen than polar air and double that of arctic air. They found that the concentration of the two ions depended on the amount of antecedent rainfall. Further, there was an almost constant ratio NH_4-N to NO_3-N of 2/1. This was interpreted as indicating a common origin; a photochemical one whose reaction was considered to be:-

$$12N + 18H_2O \longrightarrow 4\,NH_4NO_3 + 4\,NH_4OH + O_2$$

The interdependence of NH_4^+ and NO_3^- in precipitation can also be explained by the oxidation of Ammonium photochemically (Hutchinson 1954, Virtanen 1952). Gambell and Fisher (1964) studying individual rainfalls in a rural area of Virginia concluded that NH_4^+ and NO_3^- in rain are derived mostly from gaseous constituents of the atmosphere. Fixation of Nitrogen by lightning is thought to be of minimal importance. Rüssel and Richards (1919) and Virtanen (1952) conclude that the most important source of Ammonia is volatilisation from land surfaces. Larson and Hettick (1956) and Shult and Hedley (1925) consider that Ammonia comes largely from natural fires and combustion of fossil fuels.

Most studies report great spatial and temporal variability of NH_4^+ and NO_3^- in rain and it is thus virtually impossible to estimate that added to surface or ground water. The great interest paid to Nitrogen in rainwater is based on the assumption that it is an important addition to nutrient supplies to agricultural land. However, Eriksson's (1955) summary of measurements from Europe and the United States presents values from 0.7 to 18.7 lbs/acre/yr. (O.74 - 21 Kg/ha/yr) the majority of which fall in the ranges 4 - 7 lbs/acre/yr. This is much less than fertiliser applications on agricultural land which in turn is generally less than the mineral Nitrogen in soil and is only a fraction of the total Nitrogen. (Allison 1955).

There are few studies which relate inputs of Nitrogen in rain to that in surface waters. Taylor et al (1971) considering nutrients in streams draining woodland and farmland near Coshocton, Ohio, found that the Nitrogen budget was wholly dominated by the input from rainfall, which exceeded the fertiliser applied. Fisher et al (1968) measured precipitation inputs of NH_4^+ and NO_3^- and their discharge from the Hubbard Brook Experimental Forest. They showed that inputs exceeded outputs and that nutrients from rainfall were sufficient for the maintenance of natural, stable ecosystems. Fruh (1968) consider that for lakes rainfall can be a significant source of Nitrogen.

Additions of Nitrogen into a river basin from rainfall are not considered to be important in controlling levels in streams and rivers. In any basin the area covered by watercourses is relatively small and the vast majority of rain falls directly onto soil. In Britain inputs of Nitrogen in rain generally amount to 5 or 6 Kg/ha/yr whereas the total

Nitrogen in the top 150 mm of agricultural soil is from 3000 to 4000 Kg/ha (Tomlinson 1970) and up to 6000 Kg/ha in grassland. Outputs in drainage water are related to the conditions which exist in soils. Considering the complexity of soil systems, the magnitude of the soil Nitrogen reservoir and the importance of bacteriological action one is forced to the conclusion that there is no real reason to expect a correlation between inputs of Nitrogen in rainfall with outputs from cultivated watersheds.

CULTIVATED AREAS

The majority of Nitrogen in soil is organically bound. Only a small fraction is in the inorganic form (mineral nitrogen) and this varies markedly among soils and between seasons of the year for the same soil.

Climate has a marked influence on the quantity of mineral Nitrogen in the soil at any one time and upon the formation and loss process. In temperate humid climates Nitrates would generally move downwards in the soil profile with water movement during the winter when precipitation exceeds evaporation but may not move downwards during summer except with heavy rainfall (Harmsen and Schreven, 1955). Consequently, the content of mineral Nitrogen is low in winter, rises in spring and is again reduced by autumn rains. Mineralisation is low in winter and is stimulated by warmer weather in spring. The rise slows during summer and this has been attributed, in Europe, to July and August rains (Harmsen 1962). However, such generalisations are of little use in considering single years as departures from normal weather situations can be very large. Moreover, some investigators have observed large fluctuations in mineral

Nitrogen contents even under steady conditions (Diamond 1937, Griffiths 1951, Hagenziker 1957). Griffiths considers that such unexplained variations may be due to a periodicity in the mineralization - immobilization pattern in the soil.

A vast literature exists giving levels of mineral Nitrogen in the soil and difficulty is found in comparing various sorts of units and ranges of values and different experimental conditions. Cooke and Williams (1970) present a brief resume of data relevant to English agricultural land. They state that most agricultural soils contain between 0.075 and 0.3% of total Nitrogen, almost all of which is combined with about ten times as much Carbon as organic Nitrogen. A small proportion is mineralised annually and quickly nitrified. In permanent grassland soils only a very small amount is mineralised each year whereas on land used for growing cereals it is from 30 to 60 kg/ha. The average fertilizer application on all crops and grass in Britain in 1969 was 75 kg/ha.

In temperate climates on arable land the inorganic Nitrogen generally disappears rapidly as soon as the crop starts growing. Perennial crops have a developed root system which can begin absorbing Nitrogen as soon as conditions are favourable for growth. Annual crops on the other hand absorb Nitrogen slowly at first until their root systems have developed. At harvest time the amount of inorganic Nitrogen in cropped soil is negligible.

After harvest in autumn, mineralisation generally brings about a rise in the amount of inorganic Nitrogen because absorption by plants has stopped. Decay of stubble and roots may contribute to net mineralisation but this accumulation is liable to be leached by winter rains.

NON-CULTIVATED AREAS

Total Nitrogen levels are lowest on soils under continuous arable cultivation and greatest under permanent grassland. However, grassland soils are generally characterised by low levels of inorganic Nitrogen throughout the year. Grasses have a large capacity to absorb Nitrogen and mineralisation rates are generally low under them. Thus Nitrogen is more available in arable soils. Harmsen and Schreven, (1955) also report that any kind of soil tillage stimulates mineralisation.

The capacity to immobilise Nitrogen is characteristic of all permanent vegetation. Low quantities of inorganic Nitrogen have been found under prairie, savanna and forest (Harmsen and Schreven, 1955). The intensive experiment at the Hubbard Brook Forest demonstrates clearly the stability and self regulation of natural ecosystems. Small losses of Nitrogen, both dissolved and solid, are characteristic (Bormann et al 1969) although fairly large turnovers of Nitrogen within the forest are recorded.

MOVEMENT OF INORGANIC NITROGEN THROUGH AND FROM THE SOIL

The major movements of Nitrogen through and from the soil are in solution. Nitrate Nitrogen in the form most readily moved in water. Urea and some amino compounds are also soluble and move readily. However, these substances generally have a transient existence in soil as they are readily hydrolised to Ammonia. Ammonium Nitrogen can be strongly absorbed on soil colloids. In most soil. the quantity of unfixed Ammonium Nitrogen is negligible.

Amounts of Nitrogen lost depend on a large number of variables that are understood fairly well at least in a qualitative way (Allison 1966). The most important are: (a) the form and amount of soluble and unabsorbed Nitrogen present or added to the soil; (b) amount and time of rainfall; (c) infiltration and percolation rates; (d) water holding capacity of the soil; (e) presence or absence of a crop; (f) evapotranspiration; (g) rate of removal of Nitrogen by vegetation; (h) extent of upward movements during drought; and (j) whether Nitrogen is leached below the root zone especially to ground water.

In essence when considering losses of Nitrogen from fields one is dealing with an extremely complex system where predictions are difficult. A large number of studies have been conducted on Nitrogen leached from lysimeters (Harmsen and Schreven, 1955; Allison, 1966) which substantiate the nine points above. The object of lysimeter studies generally has been to investigate Nitrogen balances of soils. Allison (1955) reviews a large number of such investigations and draws a number of important conclusions particularly with regard to soils and fertilisers. Lysimeter studies show that about 15% of fertiliser Nitrogen was unaccounted for. In greenhouse experiments about 50% and in field experiments 50-70% was recovered. Most Nitrogen was lost by leaching but gaseous losses were frequently large. The inadequacy of data was emphasised.

Field studies of Nitrogen losses have been relatively few in number and great difficulties in measuring are experienced. Harmsen and Schreven, 1955, Cooke and Williams, 1970, and Allison, 1955 and 1966 review results from field experiments. It is clear that losses from cropped soils behave in much the same way as from lysimeters. Cropped soils lose much less Nitrogen than fallow and grassland losses are less than from arable land. Losses of Nitrate are greater in winter when rainfall is highest and plant growth least. Cooke and Williams (1970) referring to English work, consider that drainage from well farmed arable land will contain on average 10 mg/l of NO_3-N. Losses from light land will be less variable and higher than from heavy, but the heaviest losses of all will be from heavy land during spring.

Losses of Nitrogen from soil to watercourses are not confined to losses in solution. The quantity of Nitrogen on eroded fines is generally quite high and often leachable on entering a different environment such as a lake or river (Fruh 1968). Massey and Jackson (1952) point out that nutrients are selectively eroded from soils because they are concentrated on finer, generally colloidal material. Rogers (1941), Flippen (1945) and Moe et al (1968) show that such losses can be higher than from leachate. This Nitrogen can be released over long periods in lakes. Cooke and

Williams (1970) point out that water erosion, though rarely spectacular, occurs over most of Britain and soils must provide a lot of the sediment in rivers and lakes. This source of Nitrogen to rivers has hardly been studied in this country. Timmons et al (1970) estimated that substantial amounts of Nitrogen could be leached from a variety of crop residues in fields, which contain large amounts of extractable compounds.

Another potentially large source of Nitrogen is from farm yard manure or slurry applied to the fields. Because slurry from stock lots or pig farms presents a disposal problem it is often heaped on fields and large amounts of Nitrogen can be lost by seepage. Where animals congregate near field corners, gates and streams, their urine and excreta can be very concentrated. A very restricted literature exists on these sources (AWWA Committee Report 1967, Cooke and Williams, 1970) but they are potentially large.

Although there is a good knowledge of losses of Nitrogen from soils very few attempts have been made to relate these losses to levels of Nitrogen found in rivers or lakes. Tomlinson (1970) in questioning the way in which the suggestion that Nitrates in rivers are derived from land drainage may be examined presents two alternatives: (a) measuring the quantity of Nitrates supplied by various sources and (b) considering how Nitrate levels in rivers vary at different times of year, since in England soil drainage does not normally occur in summer.

Of the first type only one detailed study is known to have been completed; that by Owens (1970) who studied the River Great Ouse. He estimated sewage inputs from an average figure and deducted this from the total river load to compute that supplied from land drainage. There are enormous errors in this approach but it is clear that the majority of Nitrates in this river are derived from the land. Other studies by Owens and Johnson (1966), Sawyer (1947), Sylvester (1961), Sylvester and Seabloom (1963) and Flippen (1945) indicate the importance of land drainage for Nitrogen supplies to rivers.

The levels of Nitrate found in land drainage are normally high enough to account for the concentrations found in rivers (Tomlinson (1970). For a great many drainage basins land drainage is likely to be the major source of Nitrates simply because there are no others. However, one source which is often overlooked is from groundwater. Here again, the literature is far from adequate, especially for England. Of the second sort no study is known except that of Edwards (1973 b) which is largely conjectural.

GROUND WATER

As most ground water must initially move through the soil, Nitrate concentrations are possibly related to land use and all the other factors; which affect yields from soils. Wadleigh (1968) in an extensive review of Wastes in relation to agriculture and forestry quotes Public Health Officers in the United States who relate increasing Nitrate levels in wells to fertiliser use, albeit tentatively, and other studies which demonstrate no relation at all. Cooke and Williams (1970) quote Nitrate figures from wells and boreholes at three sites in England. Values vary up to 12.5 mg/l but are generally much lower. They relate higher Nitrate contents to the presence of light, sandy soils at one site and low values to a denitrifying, water logged, boulder clay horizon at another. Few other general conclusions about Nitrate Nitrogen levels in ground water are available as most attention has been paid to the influence of very local factors. A notable exception is the work of Foster and Crease (1974) on NO_3 levels in Chalk in East Yorkshire. They relate increases to increasing application of nitrogeneous fertiliser and show that high concentrations occur in ground waters which are 10 or perhaps 20 years old. Examination of chalk pore water at shallow depths below fertilised land shows NO_3-N levels locally in excess of 30 mg/l in strong contrast to low concentrations ($<$ 5 mg/l) under unfertilised land. In England the only major aquifer where high NO_3 levels are recorded is the Chalk and this may be related to the properties of Chalk soil in combination with a highly permeable rock. Green and Walker (1970) describe a situation in the Eastbourne Chalk block where high Nitrate levels in an aquifer are related to gas liquor fertiliser applications on a thin Chalk soil. Smith (1967) concluded from a large survey of wells in Missouri that the main controls over Nitrates in well water were the presence of animal wastes, improperly constituted shallow wells and septic tank drainage. Stewart et al (1967), Leclaire (1955) and Gillhorn and Webber (1969) show the importance of sources such as feedlots and organic refuse dumps in contaminating small zones of ground water. Such sources are growing in number and extent. No serious problems have been reported from England although such contamination undoubtedly exists.

One characteristic of Nitrates in ground water which needs stressing is the very high levels which can be expected locally. Green and Walker (1970) report levels over 60 mg/l NO_3-N for the Eastbourne case. Similar high levels are reported from the United States where shallow wells form an important part of the water supply system. George and Hastings (1951) report levels in public supplies in twenty seven Texas towns to be in excess of 50 p.p.m. of Nitrate (= 12 p.p.m. NO_3-N) when the USPHS standard is 44 p.p.m. Concentrations are reported in the range 90 - 130 p.p.m. NO_3 for Grover City and Arroyo Grande, California and in the range 240-975 p.p.m. NO_3 for several counties in Michigan (Deutsch 1963) by Wadleigh (1968).

Few studies have related Nitrate levels in ground water to those in surface waters they supply. Fruh (1968) reports a computation based on previous work of the hydrology of the Lake Mendots area,. Wisconsin, and concludes that ground water is the major source of Nitrogen.

URBAN RUNOFF

Runoff from urban areas has been considered an important factor in stream pollution (Fruh 1968). Definitions of urban runoff vary considerably from storm runoff from hard surfaces (Sylvester and Anderson 1964) to drainage in "Urban creeks" (Sylvester 1961). Therefore comparisons are difficult. Fruh's (1968) review lists Nitrogen levels in urban drainage from various workers and in only one situation, arterial runoff with no antecedent rainfall, is total Nitrogen concentrations greater than 5 mg/l. Reported values are generally less than 1 mg/l. Sylvester and Anderson (1964) and Weibel (1964) show that a major factor in determining Nitrate Nitrogen concentrations is the interval since and the amount of the last rainfall. Sylvester and Anderson (1964) consider the source of Nitrogen to be the fertilisation of lawns and gardens but such a source is probably better considered as land drainage. As there is no major input of Nitrogen to hard surfaces except dry fallout and dust, levels of runoff are similar to those in rainfall i.e. rather low. Peaks of Nitrogen are often experienced at the beginning of runoff (Weibel, 1964).

FARM YARD WASTES

Rainfall, soil drainage and groundwater constitute three important non-point sources of Nitrogen (Owens 1970) and are therefore generally impossible to measure and difficult to sample. Furthermore the factors which control their behaviour are extremely complicated. A second category of sources is point sources (Owens 1970) such as farm yards and sewage works. These are generally controlled and fluctuate in a more regular or easily predicted manner. In addition, they are potentially more easily measured and sampled.

Farm animals contribute large quantities of waste with high concentrations of Nitrogen. Inputs to waterways from farms depend largely on the type of enterprise. Only battery fowl, pigs, beef cattle and dairy cows need to be considered as they are the most numerous farm animals and are kept at some times in farm yards rather than continuously in fields.

Wadleigh (1968) presents the human population equivalent of these animals with respect to faecal production.* For a cow it is 16.4 for a pig 1.9 and for a hen 0.1. Farm animal populations are difficult to estimate but it can be assumed that wastes are large in relation to human wastes. In the U.S.A. farm animal wastes are ten times greater than human waste (AWWA Committee Report 1967). Few estimates of Nitrogen concentrations are published. Cooke and Williams (1970) report values for slurries in the range 1 - 9 g/l (= 1000 -9000 mg/l). The composition of slurries depends on the type of stock, their food, the amount of water introduced and the proportion of faeces, urine and bedding.

Animal wastes used generally to be made into manure with straw bedding and returned to fields. However, as it is expensive to make and handle, it is more usual to get rid of waste as a semi liquid slurry. Some sewage works accept farm wastes and few farmers have invested in tanks which can accept it. It is either stored in shallow lagoons or in some cases it is discharged directly (Cooke and Williams 1970, Wadleigh 1968). Under the conditions in drains and lagoons enormous gaseous losses of Nitrogen as Ammonia can result but concentrations remain extremely high. Slurry is also increasingly spread on the land.

During the winter, cattle and dairy cows are generally housed and slurry disposal is a problem. During the summer months cattle are in fields and cows visit the farm twice a day for milking and therefore summer discharges are very much lower than winter.

* by volume

Wadleigh (1968) cites several cases in the United States where feedlots have become nuisances because of odours and discharges. The Interstate Commission on the Potomac River Basin reported that when it rains farm wastes make the river unusable for swimming. The basin has a human population of a quarter of a million but an animal population with a waste production equivalent to three and a half millions, and no facilities exist for treating their waste.

In England farm animals are not housed in such large groups as in the United States and it is difficult to imagine a situation developing comparable to that in Metropolitan Los Angeles where Grandena and Torrence Counties have elected ordinances requiring all dairy farmers to move out because of the nuisance they cause. Feedlots with over one thousand head are not uncommon in the U.S.

Although considerable attention has been paid to the management of farm wastes (Norton and Hansen 1969, Webber and Lane 1969) their effects on streams and lakes has been considered only superficially (Galegar 1969, Munshall 1970, Moe et al 1968, Rensink 1966). Attention is generally confined to domestic sewage whose individual effluents are larger. Farm wastes are distributed fairly evenly over a drainage basin and the effects are less noticeable even though the total input may be as great. Studies of groundwater pollution emphasise the local nature of contamination by farm wastes.

SEWAGE EFFLUENTS

Sewage effluents are generally recognised as one of the most significant sources of Nitrogen to rivers and lakes. Levels of Nitrogen are generally high. The Royal Commission standards are of B.O.D. levels (30 p.p.m.) and suspended solids (20 p.p.m.). Low B.O.D. levels are associated with higher Nitrate contents and vice versa. In modern sewage works these standards are usually kept but are frequently exceeded in older ones, when effluents can have low Nitrate and high Ammonia contents. Various typical concentrations of Nitrogen are quoted. Owens (1970) calculates inputs of Nitrogen from effluents on an average value of 33 mg/l total Nitrogen. Fruh (1968) and Fitzgerald and Rohlick (1958) report ranges from 15-35 mg/l and 20-50 mg/l respectively.

Schwinn and Dickson (1972) suggest that concentrations of Nitrogen are independent of flow and that there are no marked daily or seasonal variations. Effluent flow, however, varies markedly during the day and the season. The daily pattern depends on the type of uses, the time of travel of effluent to and through a sewage works and the nature of the purification system. There are one or two peaks during the day. The first is in the middle or late morning and the second is in the late afternoon. Winter flows are higher than summer.

In rural areas domestic and industrial mains drainage operates only in larger settlements. A great many houses and other buildings are serviced by septic tanks and some even discharge kitchen wastes directly into ditches. These additions are generally localised and very small.

Many studies relate Nitrogen levels in lakes and rivers to that supplied from sewage works (Fruh 1967, Sawyer 1962, Sylvester 1961, Thomas 1962, Hassler 1932, Owens 1970, AWWA Committee Report 1967, Lester 1967, Tinker 1971, ledger 1972, Wagner 1970, Kolenbrander 1972, Miller 1971, Grimas et al 1972, Findenegg 1971, Gachter 1971). Fruh (1968) quotes Wuhrmann's figures relating inputs of nutrients from humans and agricultural runoff. Wuhrmann calculates that ten people per acre are needed to contribute the same amount of Nitrogen to watercourses as agricultural runnoff. Thus in rural watersheds one can expect the dominant source to be land drainage. Owens (1970), Davis and Slack (1969), Edwards (1973), Taylor et al (1971), Kohl et al (1971) and Owens and Edwards (1970) confirm this. Owens' and Edwards' (1970) survey of English rivers, although not concerned with Nitrates shows clear differences between rural and urban catchments.

Ammoniacal Nitrogen loads for urban catchments are much higher than total Nitrogen loads reported elsewhere for rural ones.

OTHER SOURCES

There are many other sources of Nitrogen which merit less attention. They are hardly mentioned in most of the literature. Sources such as silos and garbage dumps can be considered together with farm yard washings. Natural sources from higher animals or decay of vegetation can be considered as miscellaneous inputs to the soil. Most published information shows that the major sources of Nitrogen to rivers and lakes are from agricultural drainage, farm effluents and sewage effluents. In specific circumstances others may become more important and these three less so.

SUMMARY

A great deal of information is available on the various sources of Nitrate but there are no systematic studies which allow a comparison of all the important factors affacting these sources nor of what concentrations can be expected in uncontrolled field situations. From the literature review it is possible to extract a number of conclusions about the concentrations that may be observed under conditions such as those found in the basin of the Rother:

a) concnetrations of Nitrates in a river are unlikely to be related to those in rainfall.

b) the most important point sources are likely to be sewage treatment works.

c) farm drainage will be important only locally

d) land drainage will be an important source of Nitrates to rivers especially from arable land.

e) soil Nitrate levels will tend to increase in early spring due to increased mineralisation rates.

f) nitrate levels will tend to diminish during the late spring and summer as root systems become established.

g) after cropping continuing mineralisation in the soil will tend to increase the Nitrate levels in the soil.

h) losses of Nitrate from arable land will be greatest in winter when plant growth is least and rainfall highest.

i) losses of Nitrates will be greatest and most variable from light land but of maximum concentration from heavy land in spring.

j) soils with higher percentage of fines will have higher Nitrate mineralisation.

k) Nitrate losses from soils depend on the water transmitting properties of particular soils as well as rainfall and their Nitrate levels.

PART 5

HYPOTHETICAL RELATIONS

Useful predictive models depend on the availability of sufficient information of reliable quality. Prediction of Nitrate concentrations in water draining from a large agricultural watershed, where land and groundwater drainage are the dominant sources of water, depends on information about the particular factors controlling these sources. There are many such factors and useful information about some of them can be gained from existing surveys such as geological surveys, land-use surveys and hydrometric surveys.

Three such surveys have been chosen:

- the geological survey of Great Britain
- a land-use survey of the Rother Basin
- the continuous record of discharge for the Rother at Iping

The information they contain, together with time of year is taken as the input to a predictive model.

In essence, the prediction of Nitrate concentrations in a river, against the properties of the basin it drains, consists of establishing a correspondence between the two, whether a deterministic or probabilistic model is adopted. A set of parameters which describe the basin have been chosen. Their usefulness will be tested by examining whether the concentration of Nitrates in the river and the patterns of change can be associated only with realistic combinations of these parameters. Having chosen the parameters there are two important stages of investigation:-

1. establishing experimentally that the physical relations implied in such a choice do in fact hold.
2. establishing a method for using the parameters to generate values of Nitrate concentration.

The conclusions from the literature presented above do not form a coherent whole which is capable of being tested. Therefore, what are judged to be the more important and coherent relations are re-presented in the context of the available survey information. The main hypotheses based on the literature review are underlined.

The prime source of Nitrates is the soil whether water reaches rivers via land drainage or deeper seepage. The soil contains a reservoir of available Nitrogen in the form of Nitrates. The yield of Nitrate from the soil depends on the amount of water passing through it and depleting this reservoir.

The pattern of land-use is complex and individual classes such as barley or pasture may receive different treatments in different parts of the area. Fertiliser applications, time of ploughing and so on, are difficult to generalise and impossible to observe at a scale such as for this study. However, an essential characteristic is assumed to be whether an area is arable or not. Therefore, two divisions of land use are considered: arable and non-arable.

Arable enterprises affect the soil's Nitrate budget by increasing the potential for water to pass through the soil and increasing the mineralisation rate. Therefore, concentrations of Nitrate in drainage water will be higher from arable than non-arable areas.

There are four main geological divisions in the study area with distinctive soil types: Chalk, Upper Greensand, Gault and Lower Greensand. Therefore a four fold division of geology is used.

The rate of water throughflow in soils depends on their hydrological properties. Permeability is largely dependent on clay content. Soils with high clay content are less permeable than those with a low clay content. Opportunity for throughflow will be more frequent on sandy soils than on loams or clays. Therefore, the soil Nitrate reservoir will be depleted less frequently on the latter types of soil. The magnitude of the reservoir depends largely on the presence of organic colloids. Soils with a higher colloid content will present a higher potential for mineralization. Therefore, concentrations of Nitrate in drainage water will tend to increase with increasing colloidal content of the soils of an area, in the order, Lower Greensand, Chalk, Upper Greensand, Gault. (see table 5i).

The effects of season and discharge are closely related but any season may have wet or dry conditions. Four seasons are used:

I	October	to	December
II	January	to	March
III	April	to	June
IV	July	to	September

The amount of Nitrate in the soil is controlled by the rates of mineralisation, through microbiological activity and uptake by higher

TABLE 5i

MECHANICAL ANALYSIS OF SOILS FROM EACH GEOLOGICAL DIVISION

(i) Based on information supplied by S. Nortcliffe and J. Hughes (KCL)

GEOLOGY	Chalk	Upper Greensand	Gault	Lower Greensand (Hythe Beds)
VEGETATION	Permanent Pasture	Permanent Pasture	Wood-land	Fallow
LOCATION SU	829186	829186	801212	818248
ANALYTICAL DATA				
pH	7.4	7.0	5.1	6.8
% organic	19.1	0.3	0.6	0.2
% N (Kjeldahl)	3.2	0.2	0.2	0.0
% sand	7.0	18.0	17.0	77.0
% silt	59.0	52.0	23.0	17.0
% clay	34.0	30.0	60.0	6.0

continued/...

TABLE 5i (continued)

(ii) Based on information supplied by Fisons Ltd, - Levington Research Station.

GEOLOGY		Chalk	Upper Greensand	Gault	Lower Greensand (Folkestone Beds)	Lower Greensand (Sandgate Beds)	Lower Greensand (Hythe Beds)
VEGETATION		Permanent Pasture	Permanent Pasture	Perma-nent Pasture	Heathland	Permanent Pasture	Plantation
LOCATION	SU	780185	803198	795214	850222	799236	810253
ANALYTICAL DATA							
pH		7.8	7.0	5.9	4.6	6.5	5.4
% organic		2.6	2.4	2.3	1.6	1.8	0.1
% sand		18.7	30.3	29.8	87.2	78.2	85.2
% silt		64.3	34.7	23.9	6.5	5.5	1.7
% clay		12.2	27.2	44.1	5.2	16.1	15.1

plants. These rates are strongly seasonal and thus the potential for leaching will vary. Microbiological activity responds much more quickly to environmental changes than that of higher plants and therefore an excess of Nitrates can be expected in spring when the ground warms up. When arable land is cropped in Autumn this activity will continue and excesses of Nitrate will tend to build up in the soil at this time also. During the autumn and early winter processes of decomposition will increase Nitrate concentrations in the soil. Net mineralisation rates are therefore highest in early spring and late autumn - early winter. However, the opportunity for leaching is higher in autumn when the expectation of rainfall is higher. Therefore, <u>higher concentrations of Nitrate will be found in drainage waters during winter months, Seasons I and II.</u>

Two divisions are used to represent discharge in the basin: delayed flow and quick flow. This is a departure from the usual geomorphological practice which emphasises the minute and subtle effects of discharge variations on water chemistry. It is adopted in order to keep the computation simple and at this stage there is no a priori reason to expect discharge to have a greater effect on total variation of Nitrate concentration values than any other factor. Sequences of wet and dry periods can be extremely complex and it is not known if there is any threshold of discharge at any particular site which would be useful for categorising discharge effects. Therefore, the presence or absence of storm events, involving quickflow, for the whole basin, i.e. from the record of discharge at Iping, is used as the only criterion.

Except where soils are saturated or subject to continuous leaching the effect of increased throughflow of water will be to increase the concentration of Nitrate in leachate up to the point where the soil Nitrate reservoir is not replaced as fast as it is depleted for any particular rate of throughflow. Associated with increased throughflow rates will be extensions of drainage networks within the soil where new reservoirs of Nitrate are tapped. Therefore, concentrations of Nitrate in drainage waters will increase with increasing discharge under the conditions assumed in the study area. Discharge is more variable in winter generally and therefore this relation will have a strong seasonality.

A valid predictive model based on the survey information must rest on tested relationships between the four factors and NO_3-N concentrations in drainage waters. In rivers many other factors may act independently or in combination to affact NO_3-N. Therefore, it is necessary to test the hypotheses using observations taken under controlled conditions.

PART 6

SAMPLING

There are two systems being investigated, the main drainage network and the sources to it.

The main purpose of the investigation is to examine the relations between Nitrate concentrations in the main drainage network and the set of parameters describing the basin as the basis for a predictive model. The relations between the Nitrate concentrations in springs, field drains and sewage effluents with the same parameters must be examined first in order to establish the physical validity of the model.

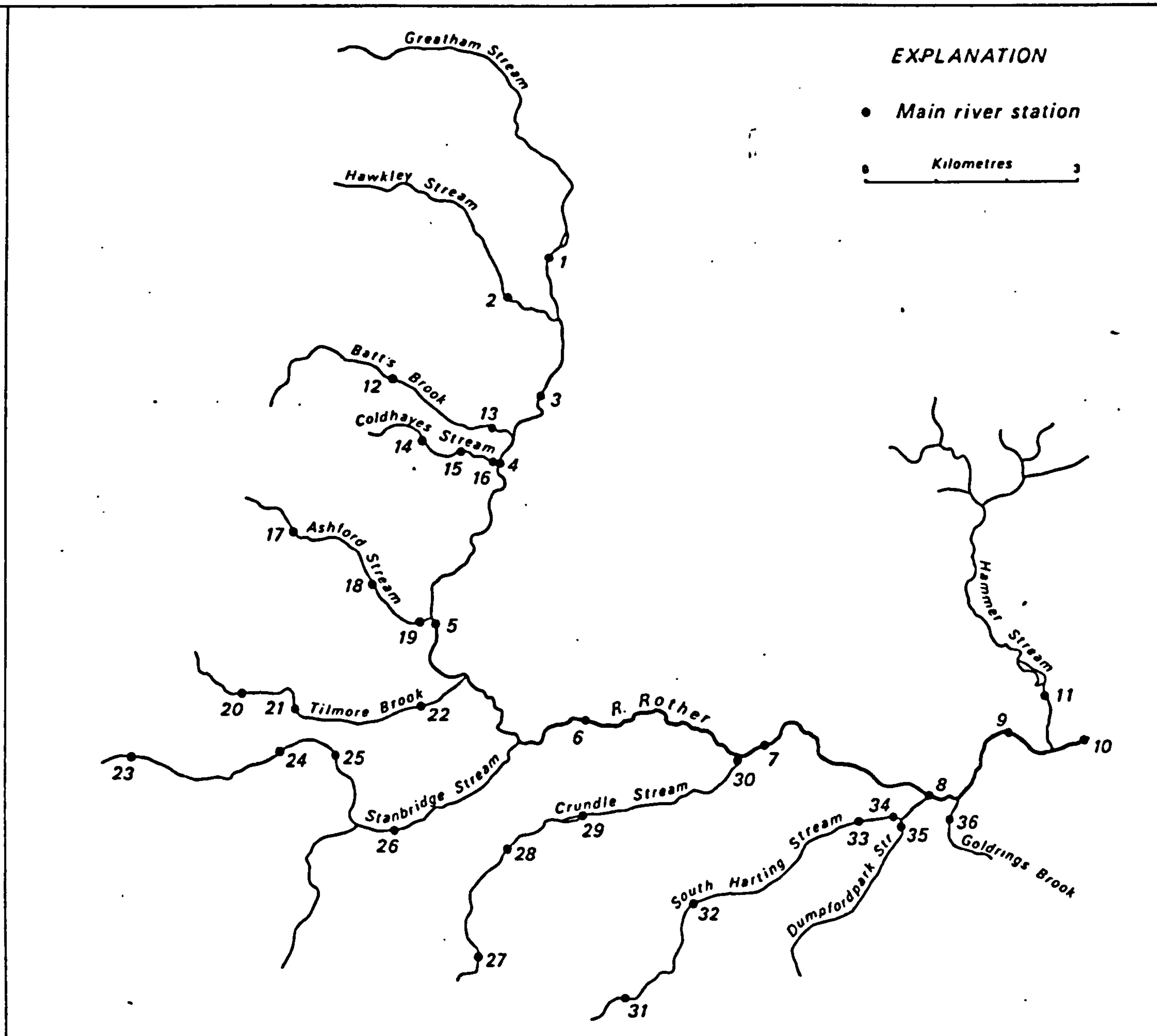
In making both sorts of observations it is necessary to sample. Both are continuous temporally and the main drainage network is continuous spatially. In particular the systems are very large and only a limited number of sampling sites could be chosen.

The area possesses a simple pattern of geological outcrops (Fig. 2 i) and most of the tributaries pass across the same sequence of rocks from Chalk to Lower Greensand. However, choosing stations at points where streams crossed geological boundaries did not provide a division of the basin into areas of homogeneous lithology because of the complex pattern of drainage divides. A sampling pattern was chosen which was as regular as possible within the limits of accessibility provided by the road network (Fig. 6 i). A total of thirty six stations was used. Selection of sampling stations provides a division of the drainage network

Fig. 6i Sampling stations on main river and tributaries.

MAIN RIVER STATIONS

1 Greatham Stream
2 Hawkley Stream
3 Liss
4 Prince's Bridge
5 Sheet
6 Durford
7 Habin
8 Terwick
9 Chithurst
10 Iping
11 Hammer Stream
12 Barefoots
13 A 325
14 Coldhayes
15 Flexcombe
16 Prince's Bridge
17 Roke
18 Harrow
19 Mill Lane
20 Berelands
21 Frenchman's Lane
22 B 2146
23 Stroud
24 Borough Road
25 A 3
26 Torberry
28 Goose Green
29 Park Bridge
30 Mizzards
31 South Harting
32 Week s 's Common
33 New Barn
34 Southdowns
35 Dumpfordpark Stream
36 Goldrings



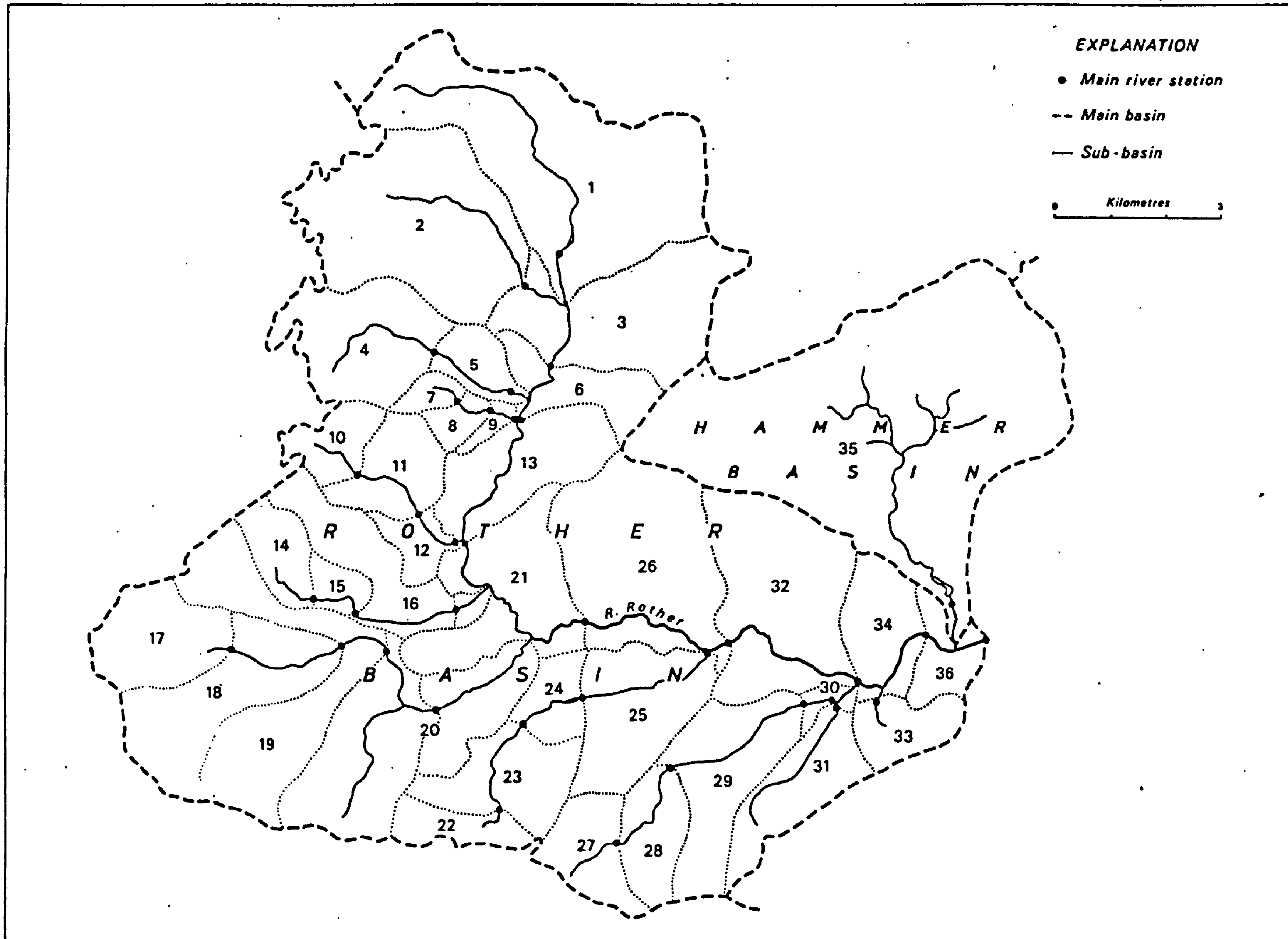
into reaches and sub-basins (Fig. 6 ii).

It is frequently desirable to have continuous information on water quality variables but this was not available. The time interval of sampling was governed partly by logistic considerations. Over a period of one year it was possible to sample on a regular basis only as frequently as once a week. No shorter sampling interval could be considered because of manpower and costs.

The observations provide a systematic sample of the years population of Nitrate concentration at several stations throughout the basin. The representitiveness of these samples therefore, depends on the sources of variation between weekly observations and the variations along channels. Of the first, two kinds of variation are probably important: those in response to discharge flutuations and those caused by fluctuating point sources such as sewage effluents. There are some isolated anomalous readings. One , at A325, on the 20th March 1973, is explained by the discharge of an extraordinary amount of farm waste into the water which reduced its oxidised Nitrogen content. This effect was observed only once at such a large scale. Other anomalies are explained as errors caused by deterioration or contamination before analysis. Occasionally bottles were misplaced for several days. Estimates have been substituted and are indicated in the table of data (Appendix 2).

The main river and its tributaries were sampled at the same

Fig. 6ii Drainage network and pattern of sub-basins


EXPLANATION
Main river station
Main basin
Sub-basin
Kilometres
0
3
R O T H E R
B A S I N
H A M M E R
B A S I N
R. Rother
1
2
3
4
5
6
7
8
9
10
11
12
13
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36

time each week, Tuesday afternoon. This time was chosen for the following reasons. At weekends the supply of Nitrogen from domestic and non-domestic sources may differ from the normal weekday pattern. An afternoon was chosen because by that time of day the peaks of sewage effluent had been discharged and passed down the river. A sample at Durford, for instance, would show little difference from that at Sheet (above on effluent) during the morning but by early afternoon a peak of Nitrate concentration would have reached Durford and samples at this time would reveal the existence of an effluent between the two stations. The relation of the station positions to the effluent positions and the time of travel of Nitrate concentration varies with discharge state and season (Fig. 6 iii). Therefore no one sampling time is entirely satisfactory but the early afternoon, 1400 - 1600 hours, appears most satisfactory for most of the sites chosen for showing the effect of the sewage effluents.

The validity of any modelling of Nitrate concentrations from reach to reach depends upon there being no irregular changes along a particular reach. Large changes do occur where tributaries or sewage effluents join the river, otherwise diffuse additions from ground and field drainage are assumed not to produce such effects. It is difficult to obtain samples to verify this assumption. A few observations of Nitrate concentrations along reaches have been made (Table 6 i) and no irregular changes have been recorded.

When smaller streams had ceased to flow and only pools existed

TABLE 6i

NITRATE NITROGEN CONCENTRATIONS ALONG SELECTED CHANNELS

River Rother from Wetrow to Durford (see Fig. 2ii)

Date-15. 5. '72

samples every 100 meters (approx)

	Station	NO_3-N;p. p. m.		
Wetrow	1	3.6		
	2	3.5		
	3	3.4		
	4	3.4		
	5	3.4		
	6	3.4		
	7	3.4		
	8	3.4		
	9	3.4		
			Stanbridge Stream	NO_3-N ; p. p. m. 7.6
10 meters below confluence		4.4		
	10	4.2		
	11	4.1		
	12	4.2		
	13	4.2		
Durford Bridge	14	4.2		

River Rother from Sheet to Durford (see Fig. 2 ii)

Date: 2. 8. 72

Samples every 300 meters (approx)

	Station	NO_3-N p. p. m.		
Sheet Bridge		3.3		
	1	3.0		
Sheet Mill	2	3.3		
	3	3.0		
	4	3.1		
			Tilmore Brook	NO_3-N p. p. m. 1.9
below confluence	5	3.0		
	6	3.1		
	7	2.9		
wetrow Bridge	8	3.0		
	9	3.0		
	10	3.0		
			Stanbridge	NO_3-N p. p. m. 9.0

continued/.....

table 6 i (continued/...

	station	NO_3-N ; p.p.m.
below confluence	11	5.0
	12	4.1
	13	4.0
Durford Mill	14	4.0
Durford Bridge	15	3.8

<u>Ashford Stream</u>

Date ; 10.6.72

Samples every 100 meters (approx)

	station	NO_3-N ; p.p.m.
Main Spring		3.0
	1	2.8
	2	2.9
	3	2.7
	4	2.7
	5	2.8

<u>Coldhays Stream</u>

Date : 10.6.72

Samples every 20 meters (see Fig 6iv)

station	NO_3-N ; p.p.m.		NO_3-N p.p.m.
1	1.8		
2	1.5		
3	6.4		
		Flexcombe Tile Drain	28.0
4	16.0		
5	15.2		
6	14.2		
7	13.4		

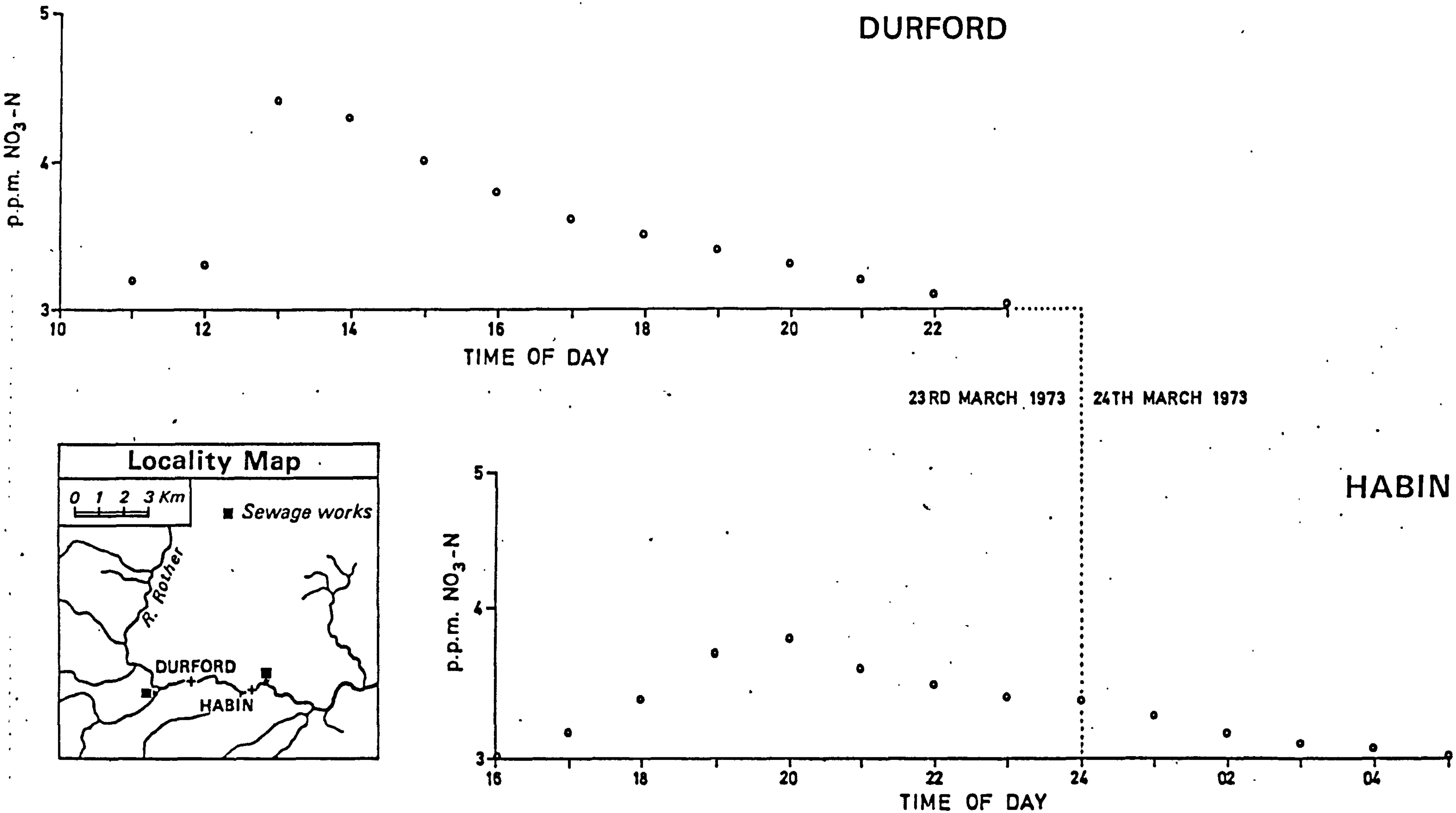

Fig. 6. iii Nitrate Nitrogen Concentrations at Durford and Habin - 23rd March 1973.

then no samples were taken. An experiment conducted to illustrate the variations that could occur was conducted on an intermittent stream with no discernible flow at the time of sampling. Samples were taken from a sequence of pools in the stony bed (Table 6 ii). It is clear that under these conditions great variation in Nitrate concentration can occur over short distances.

The sampling variability of Nitrate Nitrogen concentrations at-a-point was examined for most of the stations by taking replicate samples at the same time and at short intervals, three to five minutes, for periods of up to half an hour. The variations in these replicates (Appendix 3) did not exceed the accepted measurement error except on occasion at sites below sewage works*.

Cross channel variations were not detected. When tributaries joined or sewage effluents discharged complete mixing was observed within 20-40 m at low flow conditions (Table 6 iii).

A complementary part of the study was of Nitrate concentrations in major sources. These were classed as field drains, springs, and sewage effluents.

SPRINGS AND FIELD DRAINS

These two sources are considered together in their sampling problems. Field drains are considered to be fed by soil water predominantly, springs by ground water. It is clear, however, that there is no real division between the two and some water in any

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* Acceptable measurement error was ± 0.2 ppm. NO_3-N (Appendix 5)

TABLE 6 ii

NITRATE NITROGEN CONCENTRATIONS ALONG EAST HARTING CRUNDLE (see Fig. 2ii)

date : 10.6.72

Sample taken at 20 meter intervals (approx)

	station	NO_3-N : p.p.m.	
	7	0.94	isolated pools
	6	3.2	isolated pools
	5	1.4	isolated pools
	4	1.3	isolated pools
	3	5.2	continuous flowing
	2	5.0	water
Culvert under B 2146 (G.R. SU 804193)	1	5.2	

TABLE 6 iii

NITRATE NITROGEN CONCENTRATIONS AT JUNCTIONS OF STANBRIDGE STREAM AND RIVER ROTHER

Date : 15. 5. 72

width of river 20 meters

	RIVER ROTHER			
	South bank	Mid	North bank	Distance meters
Stanbridge Stream : 7. 6		3. 4		- 10
		3. 4		- 5
	3. 7	3. 4	3. 4	0
	6. 4	5. 3	4. 2	+ 5
	4. 7	4. 4	4. 4	+ 10
	4. 6	4. 4	4. 3	+ 20
	4. 5	4. 3	4. 4	+ 40
		4. 2		+ 80
		4. 1		+150

particular source may come from the soil or ground. In many instances the two systems may not be separate. Field drains are recognised in this study as being artificial systems for soil drainage.

Samples were taken on a weekly basis. No shorter period was considered for logistical reasons. A few samples have been taken from springs and field drains over a twenty four hour period at steady flow (Appendix 3). They show that for the sources sampled there is no change during the day not attributable to measurement error. Secondly occasional observations of sampling variability at a small number of sites showed no measureable variations in samples of ten (Appendix 3). Short term changes, less than one hour, have been observed on ten occasions (Appendix 3). They show that no trends occur at steady flow and the observations in the most extreme case are within 0.5 ppm of each other.

Selection of field drains and springs presented an enormous sampling problem. Over the large study area only a limited number of springs and drains could be sampled. A far greater number were known to exist than those actually sampled. Only a relatively small number were easily accessible. Of those which were accessible many were rejected because the area draining to them could not be defined or the land use in the drainage area of a field drain was not homogeneous.

During a one year preliminary survey only forty six sites were found in an area of 150 sq km, twenty nine field drains and seventeen springs (Fig. 6 iv). All sites are listed in Appendix 4.

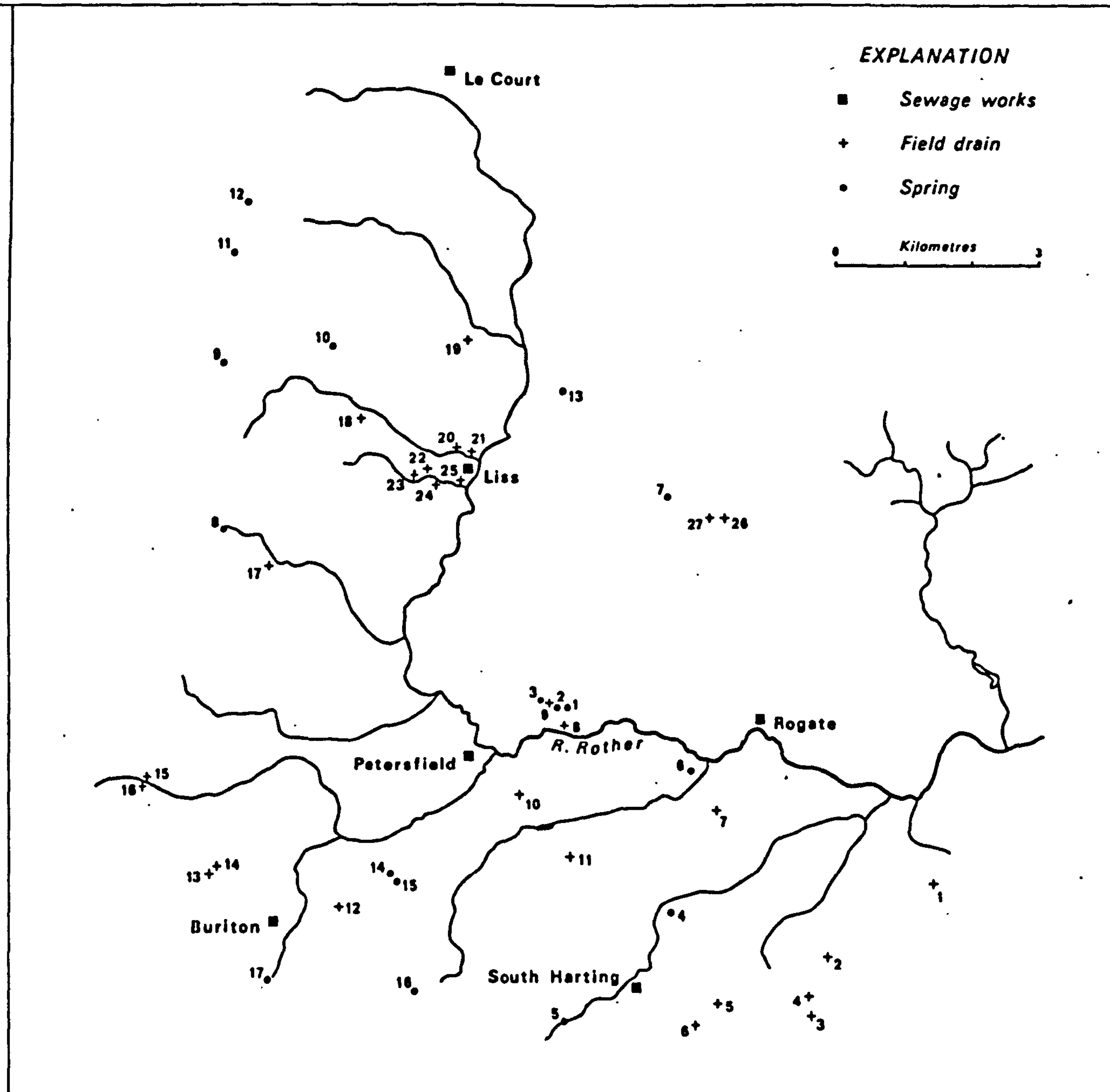
Fig. 6 iv Sampling stations at Springs and Field Drains.

FIELD DRAINS

1 Goldrings
2 Elsted A
3 Redlands
4 Elsted B
5 East Harting
6 South Harting
7 Nyewood
8 Durford Bridge
9 Durford
10 Ryefield
11 West Harting
12 Nursted
13 Westons A
14 Westons B
15 Stroudbridge A
16 Stroudbridge B
17 Roke
18 Barefoots
19 Burgates
20 A 325 N
21 A 325 S
22 Flexcombe Cottage A
23 Flexcombe Cottage B
24 Flexcombe Farm
25 Prince's Bridge
26 Common Wood A
27 Common Wood B

SPRINGS

1 Durleighmarsh A
2 Durleighmarsh B
3 Durford
4 Week s's Common
5 South Harting
6 Mizzards
7 Harting Combe
8 Ashford
9 Higher Oakshott
10 Farewell
11 Vann Farm
12 Empshott Green
13 Wyld Rose Cottage
14 Nursted A
15 Nursted B
16 Ditcham
17 Buriton



Field drain data are not completely comparable. First because the nature of the drains varied. Some were three inch tile drains some six inch and others were ditches fed by a series of tile drains. Secondly the drainage areas varied. Thirdly, some drains experienced flow when others were dry. Thus the quality of the data relating to Nitrate concentrations in field drains leaves something to be desired. However, it is as well to note that few measurements of Nitrate concentrations in field drainage water for uncontrolled conditions have been made in this country (Cooke and Williams, 1970).

SEWAGE WORKS

Sewage works have regular daily cycles of input and output of wastes (Fig. 6 v). There is often one major discharge peak and one minor. The first is during the morning when waste inputs increase from 6.00 am onwards to a maximum near 8.00 or 9.00 am, and tail off during the morning. Wastes may take a considerable time to pass through a works and effluent peaks have a lag behind input. At Petersfield and Liss works this was estimated between one and one and a half hours during low flow conditions.

Of the six sewage works in the area two, those at Petersfield and Liss, were sampled for effluent. Observations of sampling variability (Appendix 3) indicate that a single grab sample is representitive of conditions at a given time. Short period observations (Appendix 3) show that concentrations of Nitrate in effluent change little over twenty four hour periods even though effluent discharges vary considerably. Samples were taken during weekday mornings

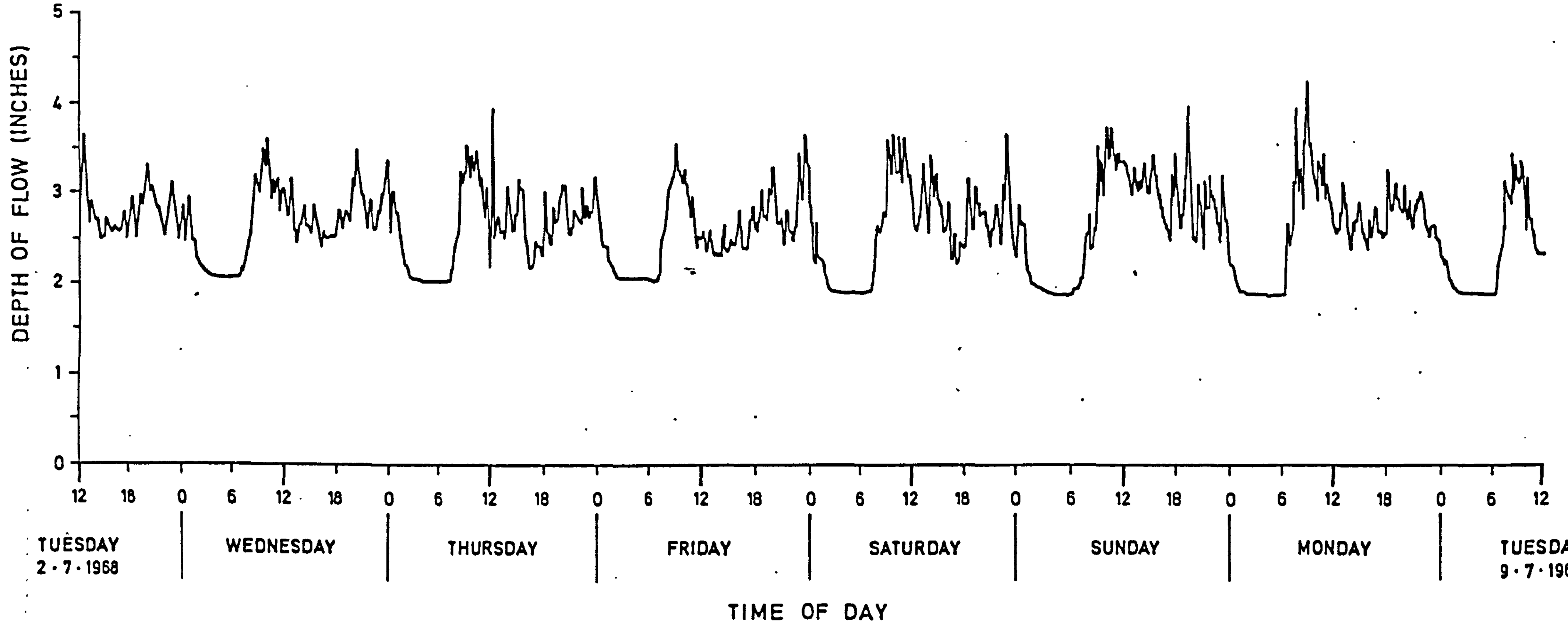


Fig. 6. v Flow from Lodsworth Sewage Works.

in order that they represent the effluent conditions corresponding to the river conditions in early afternoon.

The field investigation involved recording two other parameters: land use and fertiliser applications.

During late June and early August 1973 a land use survey of the study area was made (Fig. 2 iv). Each of the field and land parcels on the 1:10, 560 scale map was visited and its use recorded according to the following classification:

Woodland:	included natural, planted, coppiced woodland shelter belts and pieces of parkland which were heavily wooded.
Heath:	included true heaths, rough land and unimproved downland with scrub vegetation.
Orchards:	included fruit and hops.
Pasture:	included perminant pasture along with pastures of a more temporary nature with varying degrees of improvement.
Arable land:	included land devoted to barley, wheat, oats, potatoes, leguminous crops, and a miscellaneous list of other crops.
Remainder:	included predominantly roads, buildings, land surfaces such as car parks, farms, roadways, and water surfaces. Measurement of areas was adjusted so that any errors were included within this category.

The area of each unit of land was measured by a planimeter.

Further the area of each type of land use was summed for each geological division in each sub-basin (Table 6 iv). Land use data for 1967/8 was taken from field sheets of the Second Land Utilisation Survey, by kind permission of Miss A. Coleman, King's College London.

Fertiliser applications are generally regarded as an important component of Nitrogen inputs to a drainage system. The arguments of this thesis tend not to stress their importance. However, the relations between application rates and Nitrate concentration deserves attention and a survey of farm practices was carried out. It is extremely difficult to obtain concrete information. Farmers are often reluctant to reply with information and in fact sometimes found it difficult to do so because of their poor recording methods. Field data for such a large area could not be obtained. Therefore, farmers were asked to indicate the overall application rates for particular crops and particular types of land. Fertiliser information was of assay, application rate and application timing.

A postal survey of forty farmers was conducted. Sixteen full replies were received. The data is summarised in Appendix 1.

Continuous discharge and NO_3-N data for 1972/3 and discharge totals for 1967/8 were provided by the Sussex River Authority. NO3-N data for 1967/8 were provided by the North West Sussex Water Board.

TABLE 6 iv

Sub Basin	% areas underlain by: Chalk	UGS	Gault	LGS	% areas in arable use and underlain by: Chalk	UGS	Gault	LGS
1	5.2	17.4	27.8	54.6	2.1	3.6	2.7	1.1
2	18.9	40.6	36.7	1.8	0.7	7.6	4.5	
3			2.8	97.2			0.8	13.3
4	42.7	42.5	14.8		3.2	6.1	1.4	
5			82.5	17.5			20.0	1.9
6			0.1	99.9				5.8
7	9.6	46.7	43.8			2.7	3.9	
8		13.4	86.6				31.0	
9			8.5	91.5			7.2	1.4
10	73.6	26.4			12.6	1.7		
11		28.4	45.8	25.9		3.5	19.9	12.6
12				100.00				30.2
13			0.4	99.6				17.1
14	13.3	16.0	44.3	26.3			0.6	12.2
15		3.1	18.5	78.3			0.2	2.8
16	3.4	7.4	12.5	77.9		0.3		8.3
17	18.8	59.7	21.5		0.5	14.9		
18	30.5	27.4	36.1	3.9	3.2	8.2	1.3	2.5
19	35.3	27.7	21.6	15.4	4.1	6.5	0.6	1.6
20	21.0	53.0	22.1	3.8	0.4	19.7		
21				100.0				24.0
22	69.3	30.7			31.3	20.2		
23	16.0	80.4	3.6		9.1	42.4		
24		13.8	66.7	19.5		6.9	7.3	1.9
25		24.8	40.4	34.7		8.4	7.1	0.8
26				100.0				34.0
27	70.1	29.9			17.5	9.2		
28	27.5	60.4	12.1		15.9	18.0		
29	13.0	26.5	56.8	4.1	4.5	12.1	2.7	1.1

	% areas underlain by:				% areas in arable use and underlain by:			
	Chalk	UGS	Gault	LGS	Chalk	UGS	Gault	LGS
30			13.3	86.7				26.0
31				100.0				32.5
32	3.0	30.1	62.2	4.8	0.6	9.4	5.4	2.0
33			33.6	66.4			8.9	2.9
34				100.0				
35			*67.3	32.7				0.7
36				100.0				47.2

* Weald Clay

UGS Upper Greensand

LGS Lower Greensand

PART 7

ANALYSIS OF CONTROLLED OBSERVATIONS OF SPRINGS AND FIELD DRAINS.

The argument was developed in part 5 that Nitrate concentrations in rivers draining rural catchments could be predicted using a small number of variables which described the watershed and the hydrological conditions. These concentrations are clearly affected by a multiplicity of factors but it was suggested that over a large area they could be related to a small number which themselves vary at a large scale. There are no systematic experiments reported in the literature which allow a clear statement on the relations between these factors and Nitrate concentrations in drainage waters. The relations are tested by examining the concentrations observed for different combinations of the factors in a post-hoc analysis of variance.

Every factor and combination of factors cannot be represented by these observations. Springs were sampled through all four seasons but field drains flowed during only three. Gault supports no springs, Chalk no field drains. Further, the effect of land use differences cannot be distinguished for springs because catchment areas cannot be defined. Therefore, separate analyses are performed for springs and field drains.

Each combination of factors is represented by a varying number of observations but each cell of the ANOVA matrix includes five of these observations chosen at random. The data are presented in appendix 6.

A full three way analysis of variance was performed for the spring observations, and four way for field drains. A summary of the analysis is presented in tables 7i and 7iv. Where the F ratios of variances attributable to differences in the factors to the residual variances were significant at the 5% level or above, then differences between group means were tested using Duncan's Multiple Range Test. Summaries are presented in table 7ii. The data used in the analysis of variance is plotted as mean values in graphs figs 7i to 7x with corresponding graphs for the whole data set.

SPRINGS

Land-use is not considered as a factor in the analysis of variance of spring Nitrate values because it is not possible to allocate any particular sort of land use to a spring's catchment.

The three way analysis of variance (table 7i) shows only one factor, geology, to be significant, and this at the 1% level. Differences between Nitrate concentrations from the different lithological types explain 78% of the variance.

It is useful to consider the possible reasons why no other factors are found to be significant. First, there must be some suspicion that the data is not sufficiently sensitive but the four way analysis of variance performed on field drain data (see below) reveals relations with all four factors as well as interaction effects. The absence of any significant factors apart from geology suggests some other control, as Nitrate concentrations in springs are affected by soil processes as are those

TABLE 7 i

SUMMARY OF ANALYSIS OF VARIANCE ON NO_3-N VALUES FROM SPRINGS

Effect	SS	Df	Ms	F	
Geology G	102.4	2	51.21	21.97	%exp. -78%
Season S	9.3	3	3.1		n. s.
Discharge D	0.04	1	0.04		n. s.
Interaction G-S	16.3	6	2.7		n. s.
Interaction G-D	3.9	2	1.9		n. s.
Interaction S-D	5.9	3	1.9		n. s.
Interaction G-D-S	15.9	6	2.6		n. s.
Residual	223.8	96	2.3		
Total		119	65.96	--	

n. s. = not significant at the 10% level

Fig. 7 Seasonal mean values of Nitrate Nitrogen concentration.

Fig. 7i Springs - showing differences between geological divisions.

Fig. 7ii Springs - showing differences between discharge states.

Fig. 7iii Springs - showing differences between geological divisions for different discharge states.

Fig. 7iv Field Drains - overall seasonal mean values

Fig. 7v Field Drains - showing differences between geological divisions.

Fig. 7vi Field Drains - showing differences between different land uses.

Fig. 7vii Field Drains - showing differences between different discharge states.

Fig. 7viii Field Drains - showing differences between geological divisions for different land uses.

Fig. 7ix Field Drains - showing differences between geological divisions for different discharge states.

Fig. 7x Field Drains - showing differences between geological divisions for different land uses and discharge states.

NB. Delayed flow and quickflow conditions refer to the conditions at Iping Mill at the same time as other stations were sampled. These conditions are defined on p. 224.

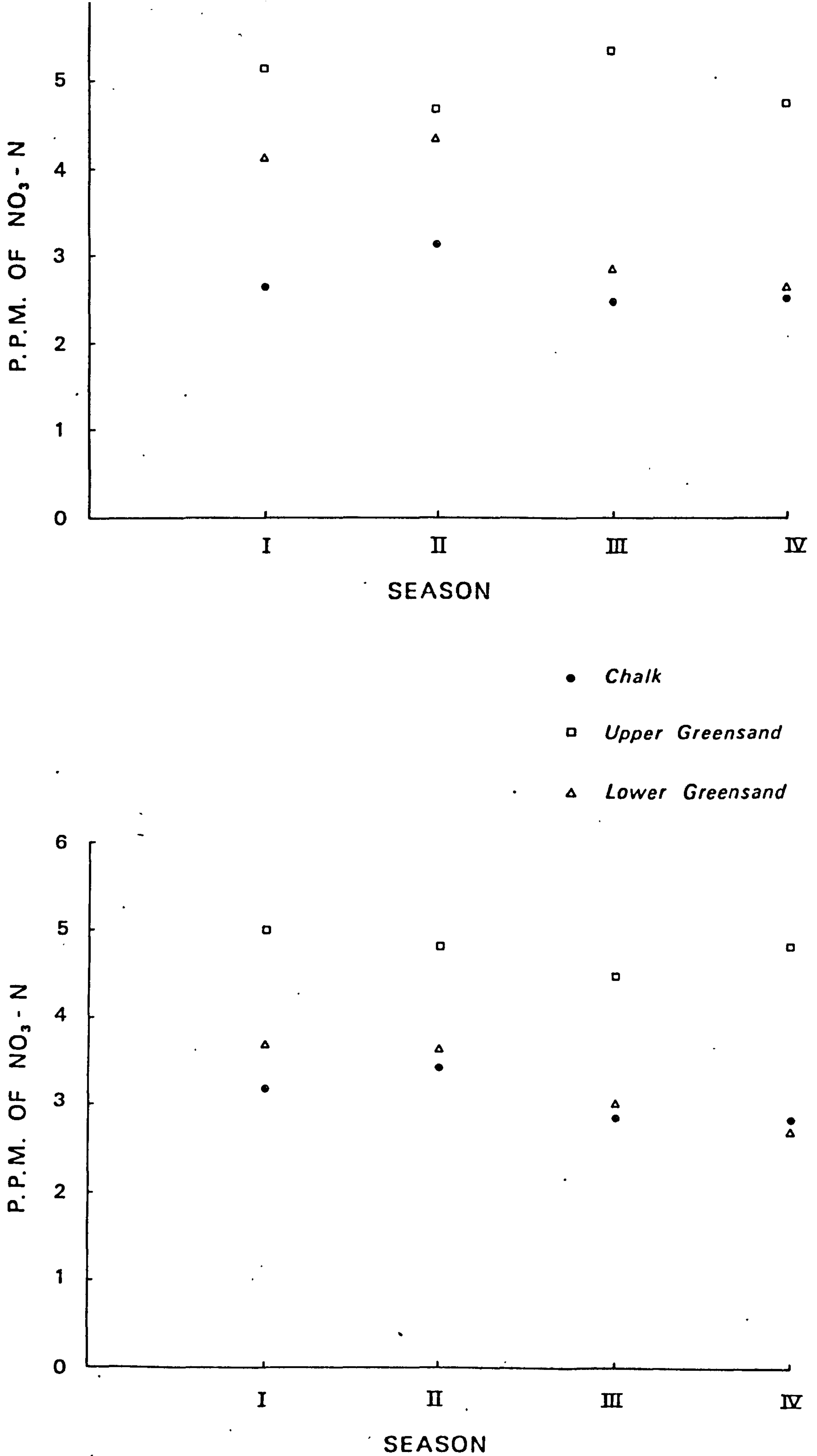
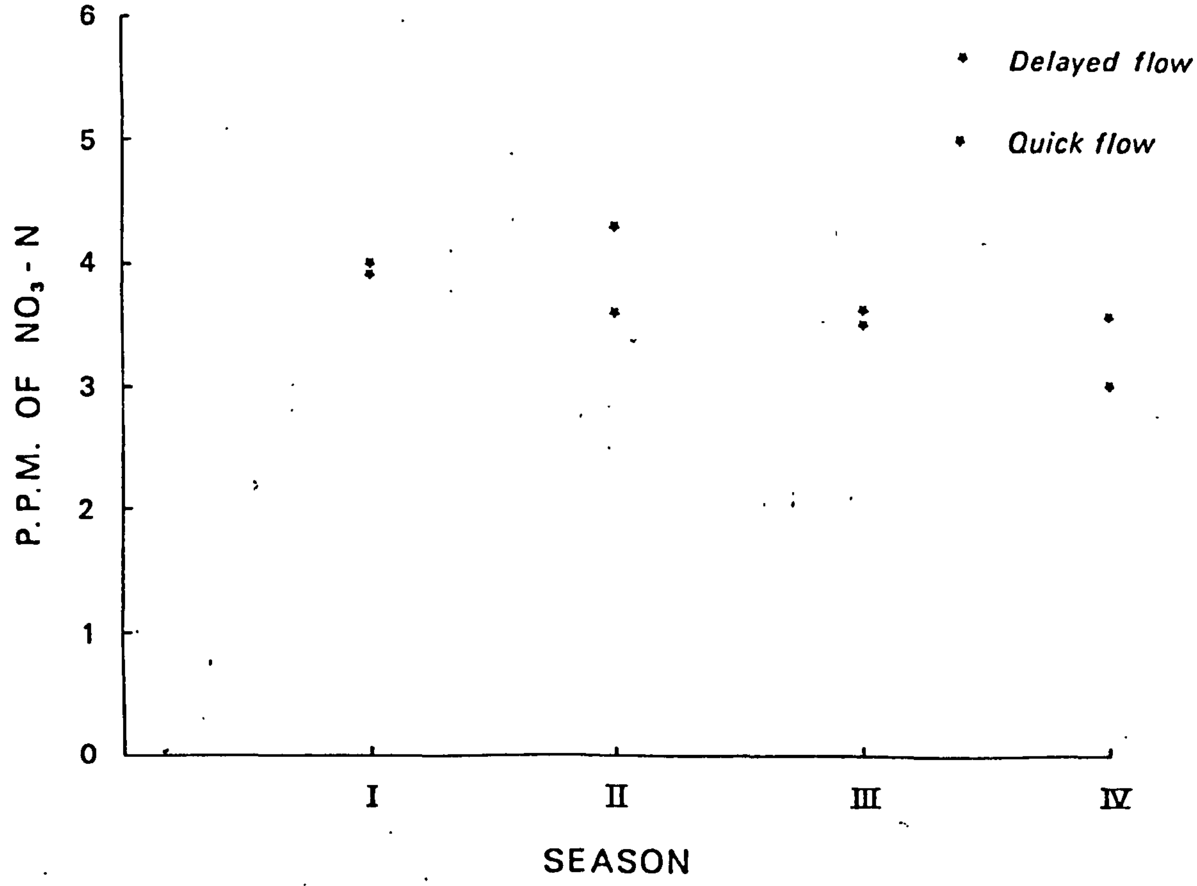

P.P.M. OF NO_3 - N
0
1
2
3
4
5
I
II
III
IV
SEASON
Chalk
Upper Greensand
Lower Greensand
P.P.M. OF NO_3 - N
0
1
2
3
4
5
6
I
II
III
IV
SEASON

Fig. 7i


6
5
4
3
2
1
0
P.P.M. OF NO_3 - N
Delayed flow
Quick flow
I
II
III
IV
SEASON

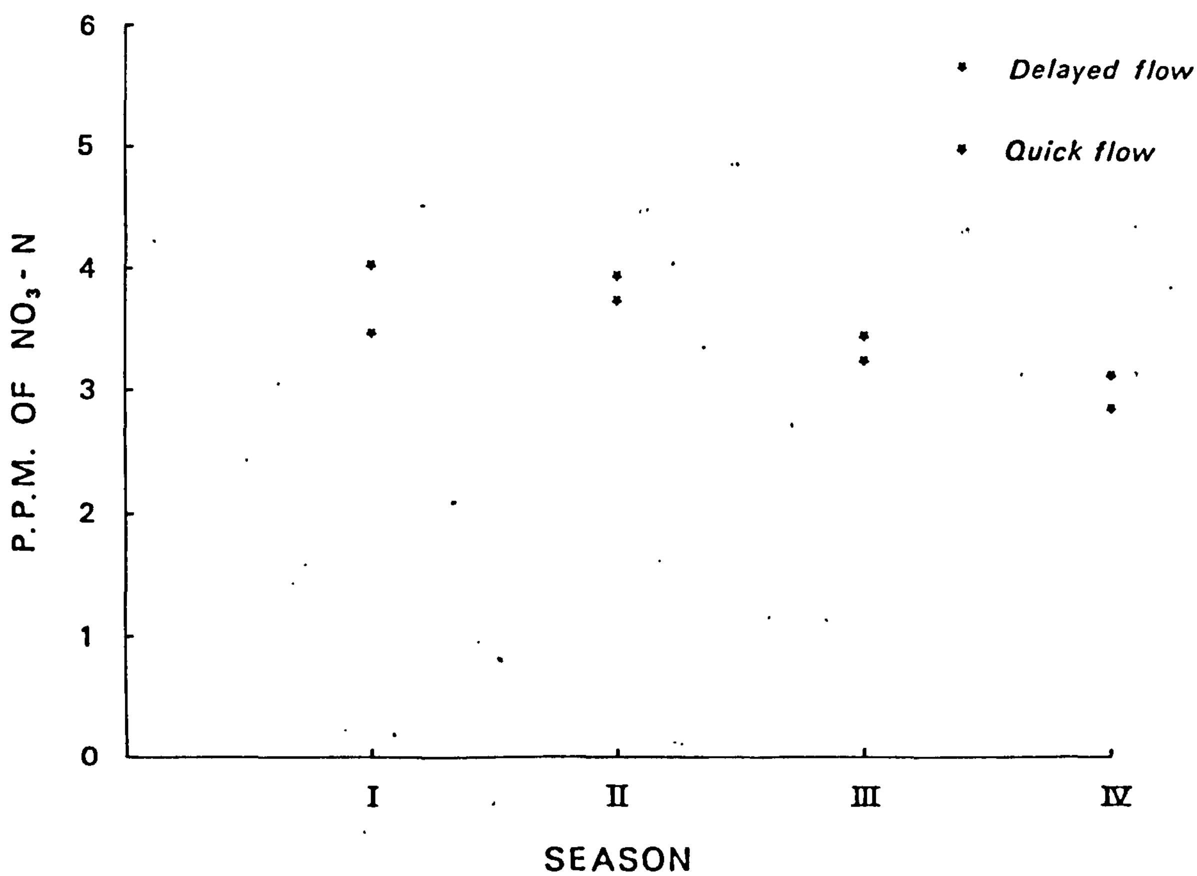

6
5
4
3
2
1
0
P.P.M. OF NO_3 - N
Delayed flow
Quick flow
I
II
III
IV
SEASON

Fig. 7ii

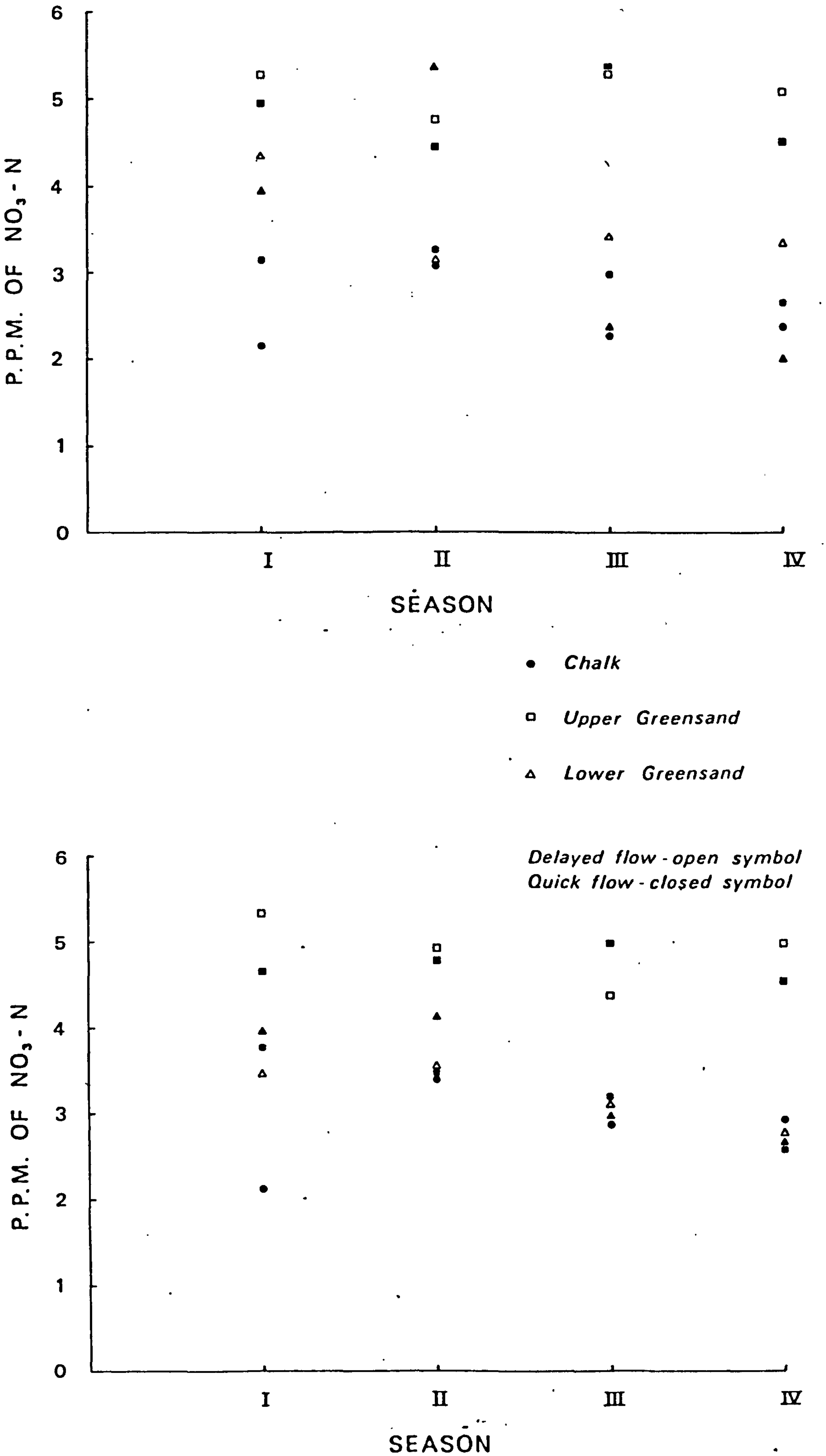

6
5
4
3
2
1
0
P.P.M. OF NO_3 - N
I
II
III
IV
SEASON
Chalk
Upper Greensand
Lower Greensand
Delayed flow - open symbol
Quick flow - closed symbol
6
5
4
3
2
1
0
P.P.M. OF NO_3 - N
I
II
III
IV
SEASON

Fig. 7iii

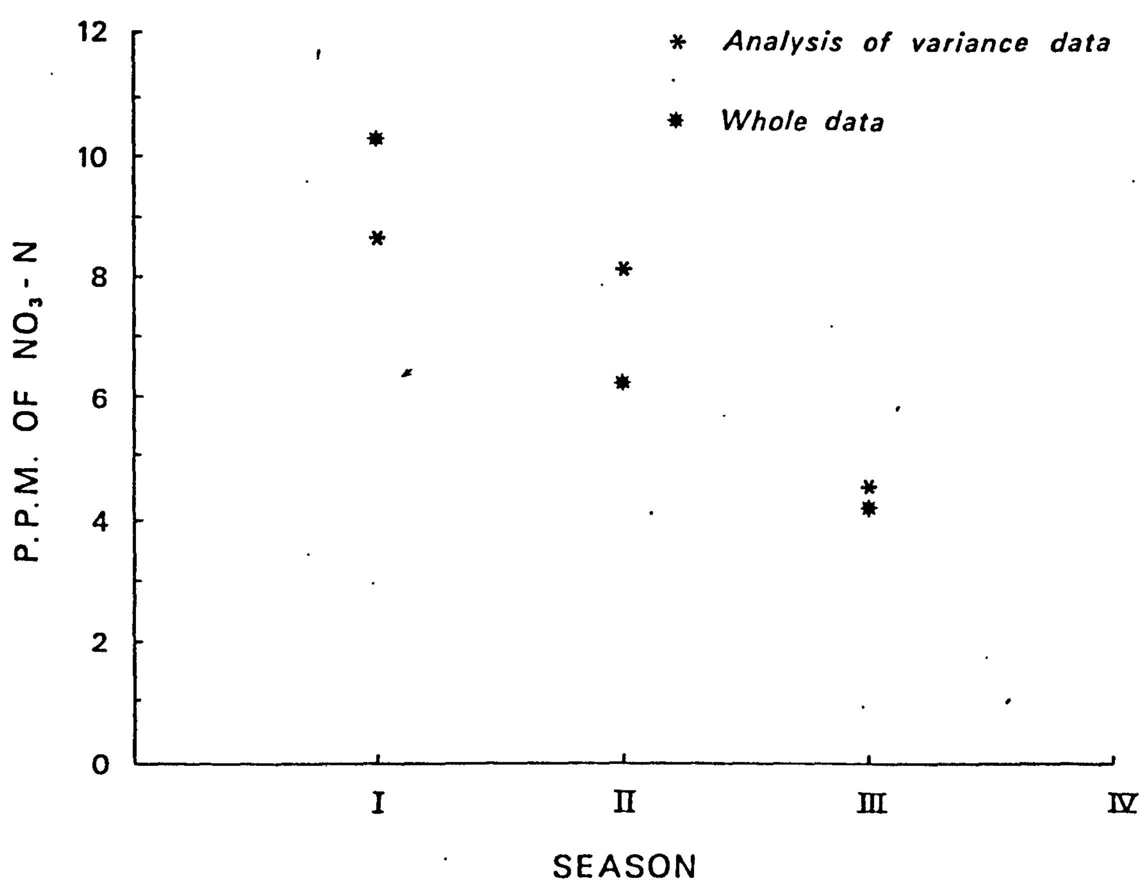
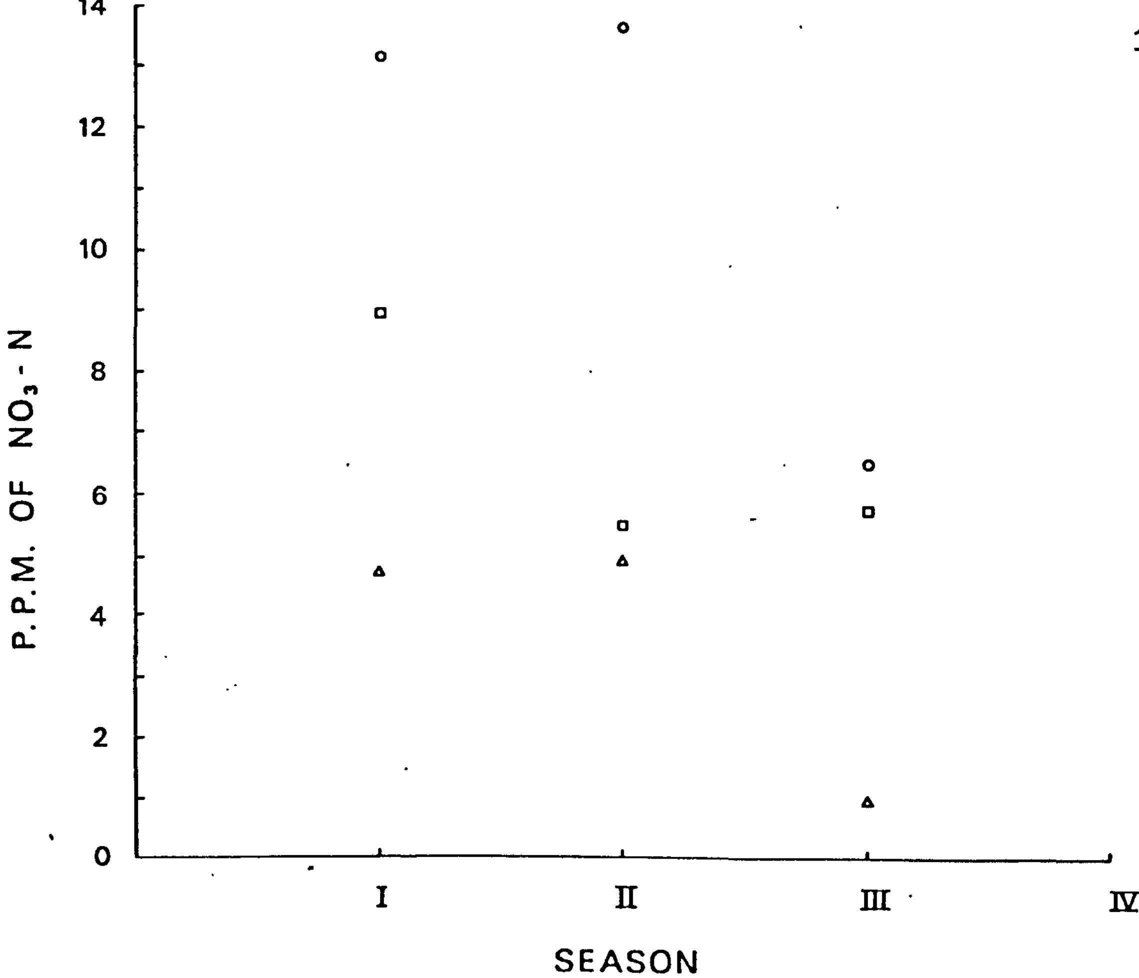

Analysis of variance data
Whole data
P.P.M. OF NO_3 - N
12
10
8
6
4
2
0
I
II
III
IV
SEASON

Fig. 7iv


14
12
10
8
6
4
2
0
P.P.M. OF NO_3-N
I
II
III
IV
SEASON

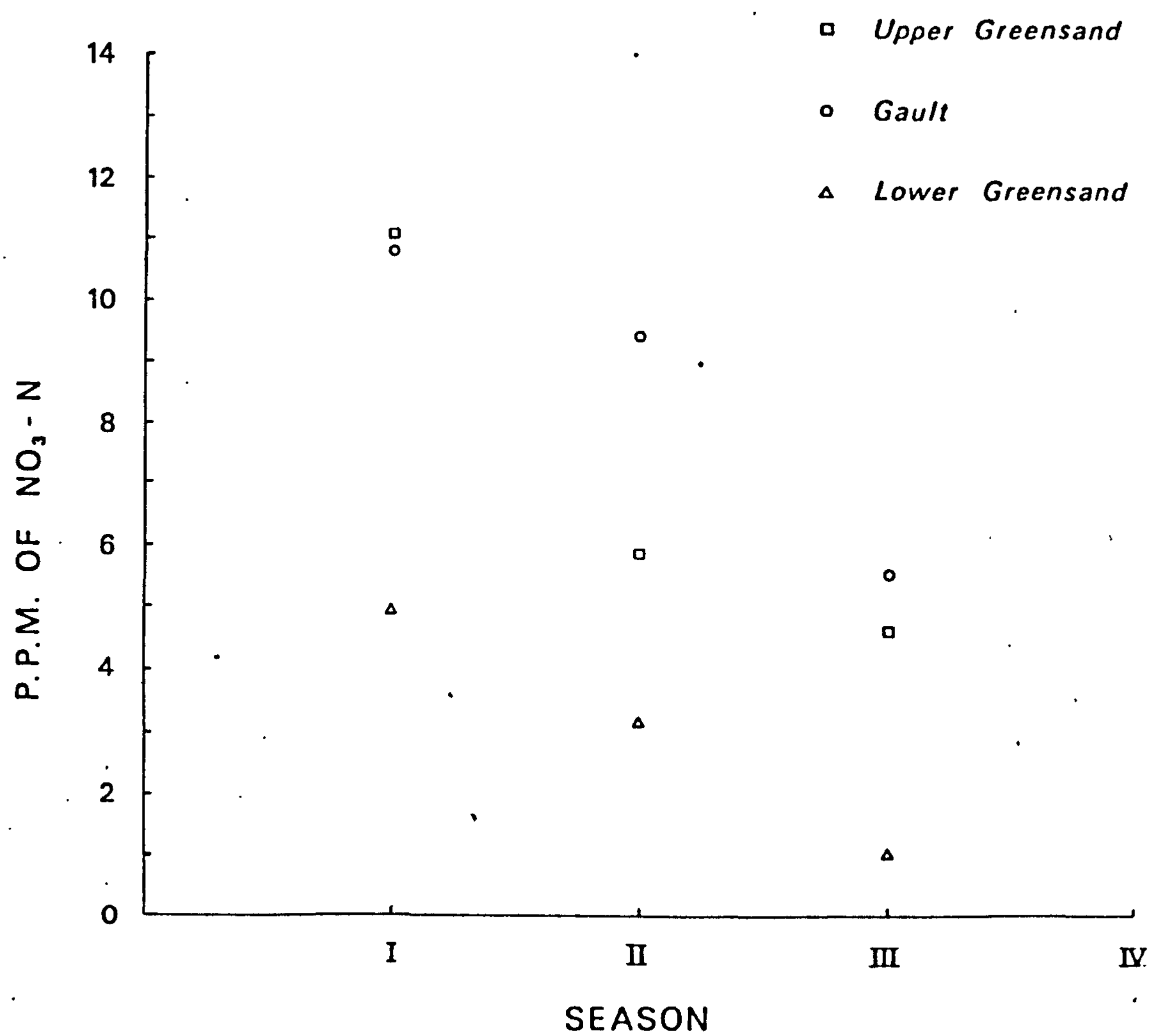
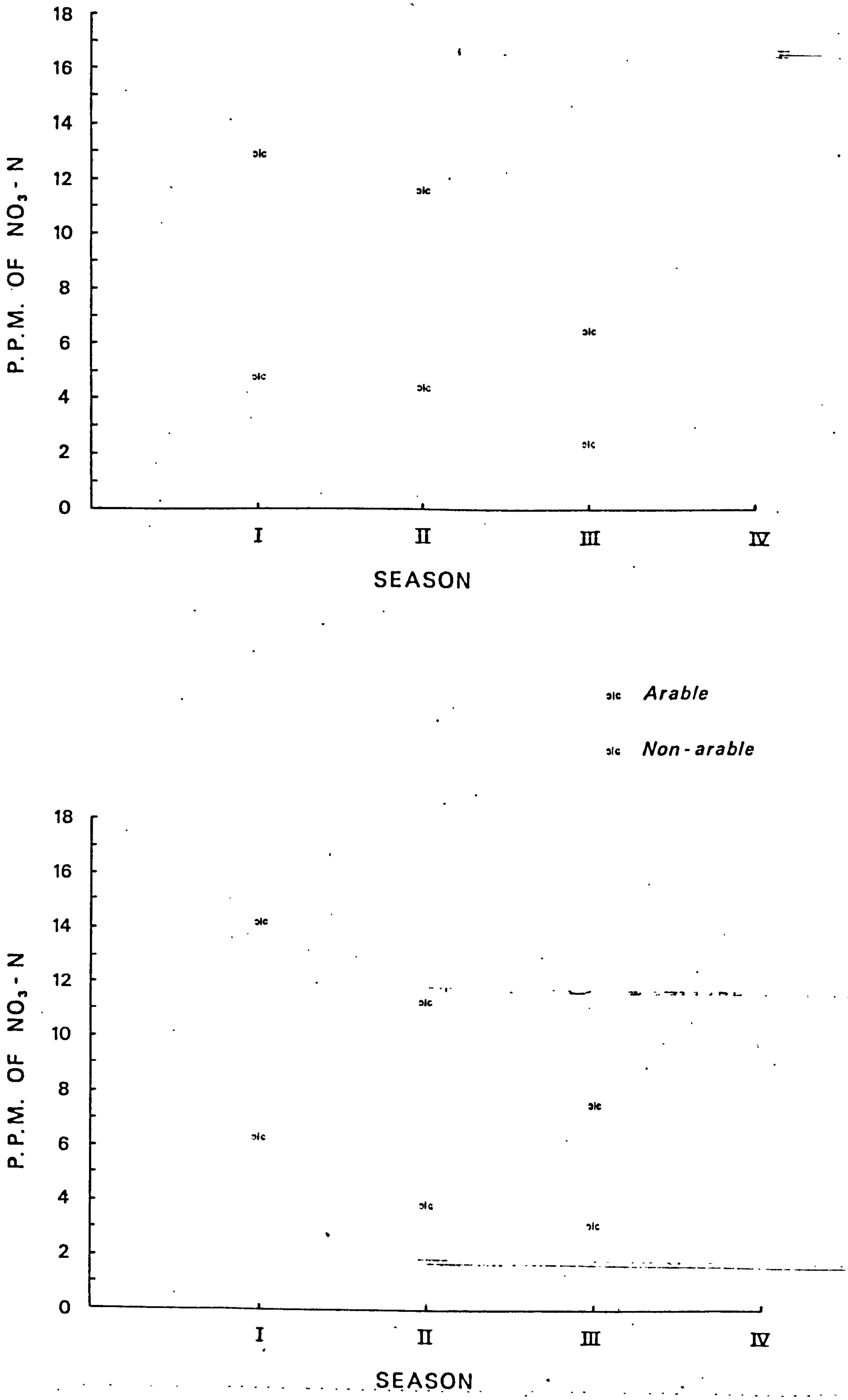
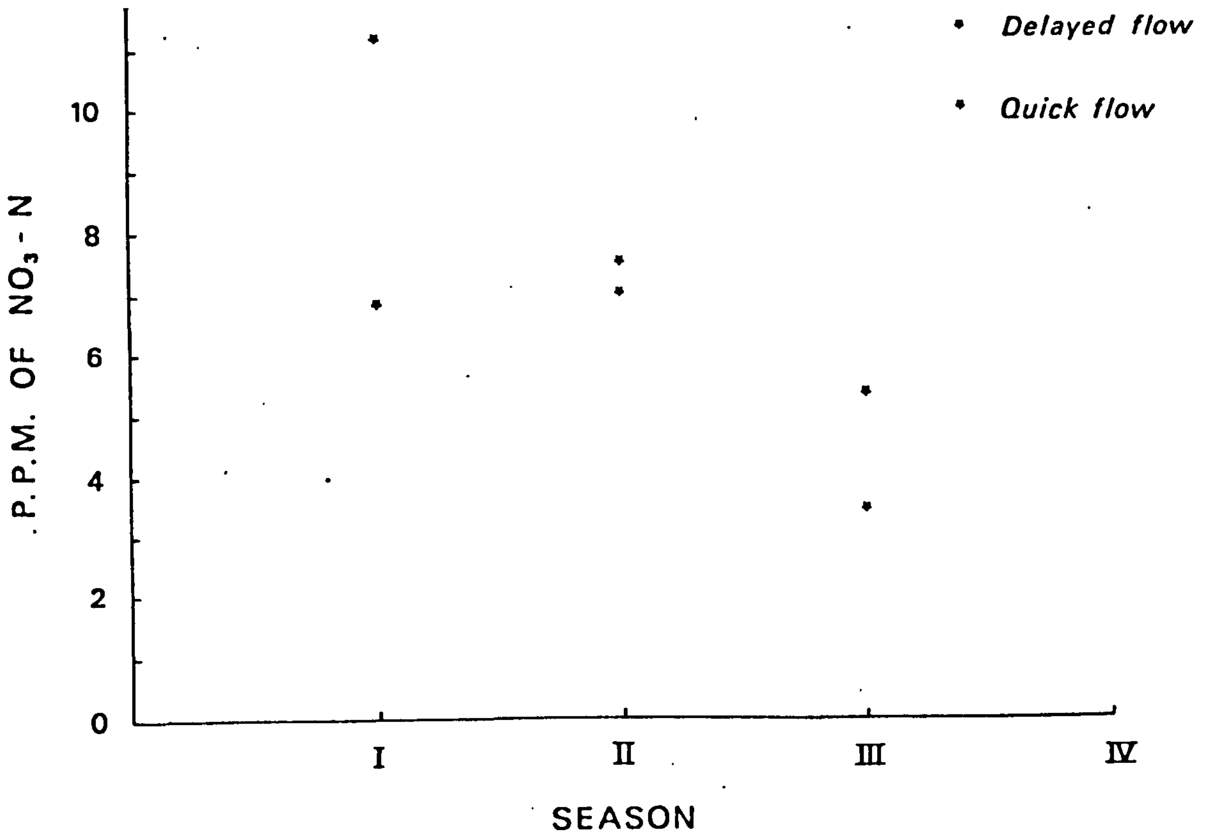

Upper Greensand
Gault
Lower Greensand
14
12
10
8
6
4
2
0
P.P.M. OF NO_3-N
I
II
III
IV
SEASON

Fig. 7v



18
16
14
12
10
8
6
4
2
0
P.P.M. OF NO_3 - N
I
II
III
IV
SEASON
Arable
Non-arable
18
16
14
12
10
8
6
4
2
0
P.P.M. OF NO_3 - N
I
II
III
IV
SEASON

Fig. 7vi


Delayed flow
Quick flow
P.P.M. OF NO_3 - N
10
8
6
4
2
0
I
II
III
IV
SEASON

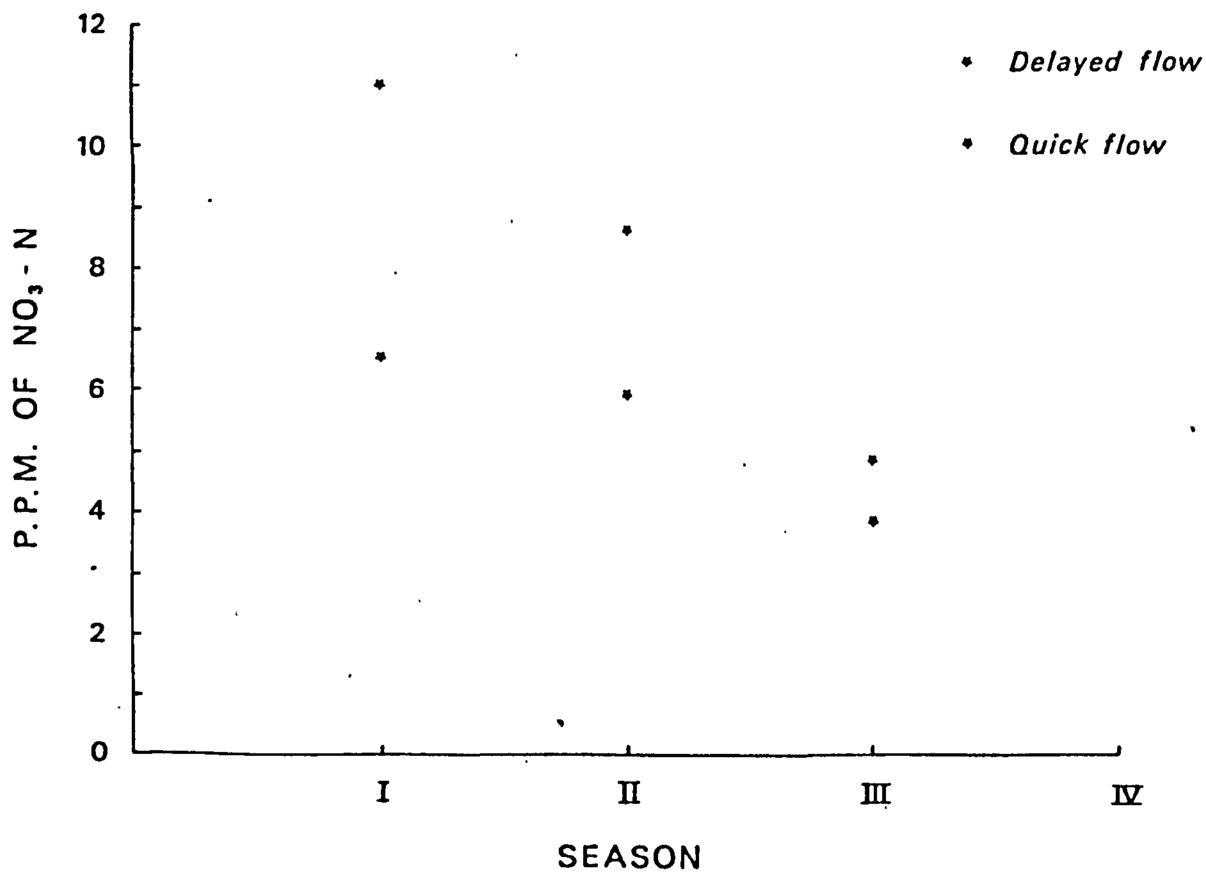

Delayed flow
Quick flow
P.P.M. OF NO_3 - N
12
10
8
6
4
2
0
I
II
III
IV
SEASON

Fig. 7vii

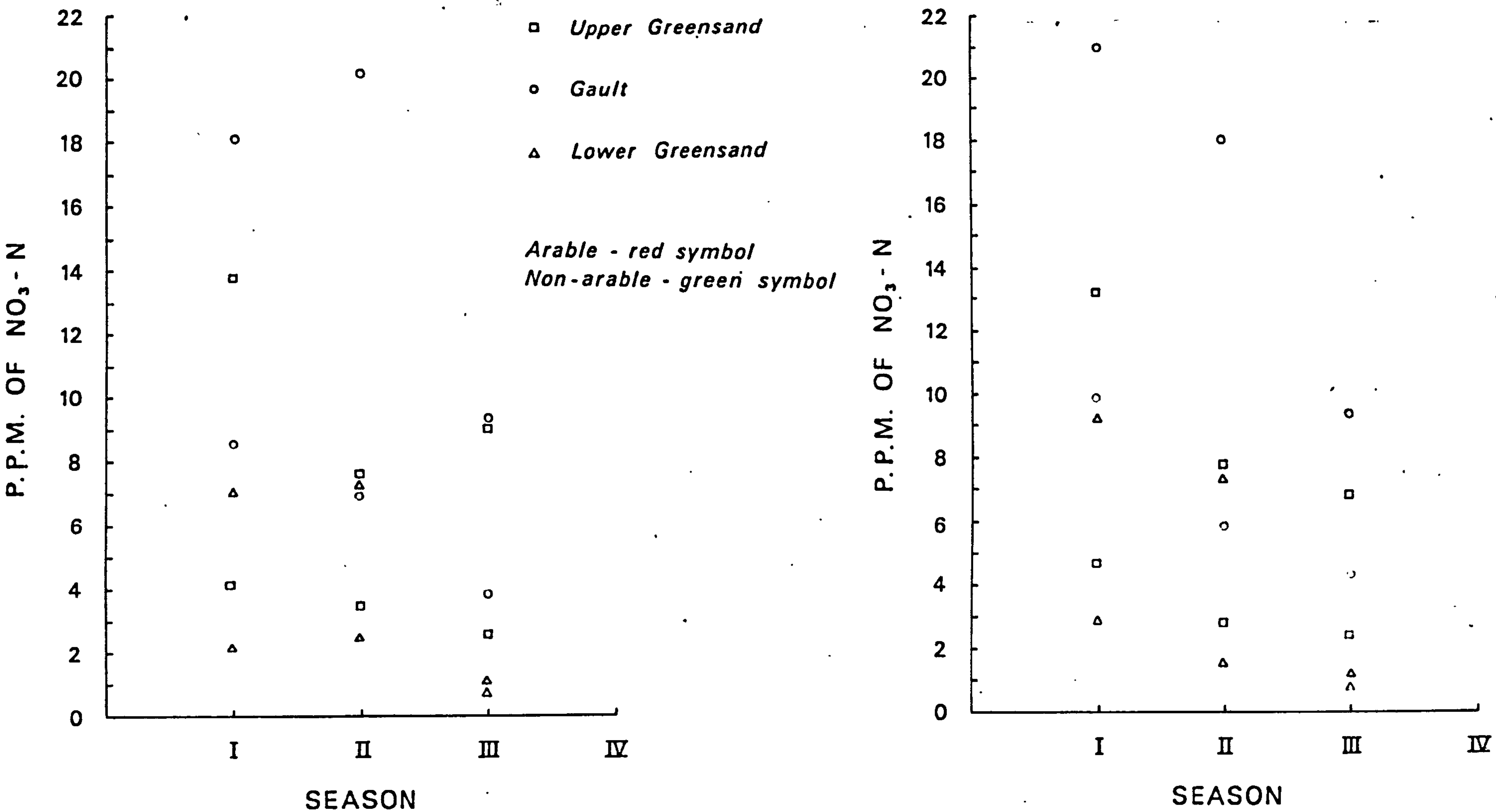

Upper Greensand
Gault
Lower Greensand
Arable - red symbol
Non-arable - green symbol
P.P.M. OF NO_3 - N
SEASON
I
II
III
IV
P.P.M. OF NO_3 - N
SEASON
I
II
III
IV

Fig. 7viii

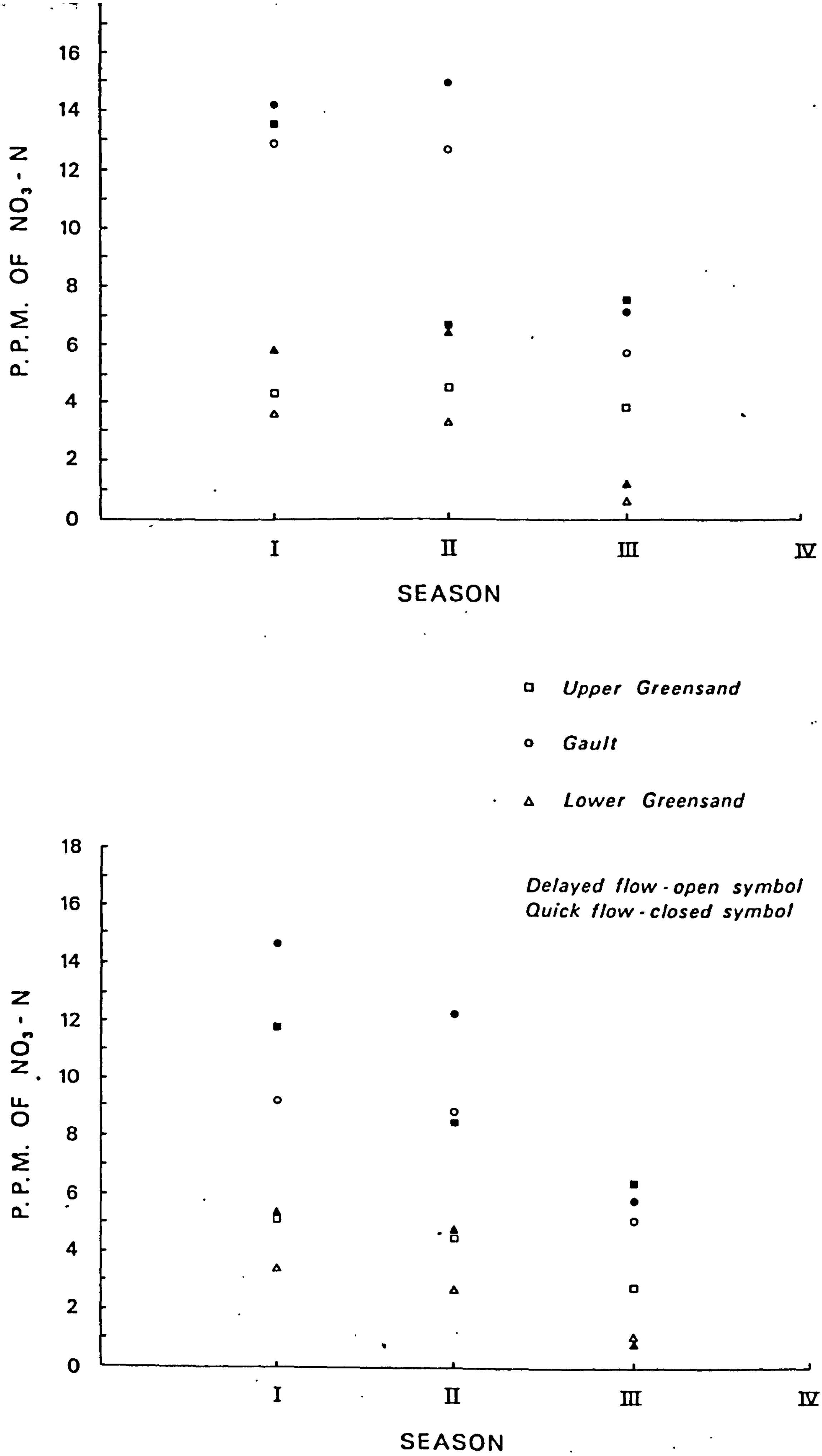

P.P.M. OF NO_3 - N
16
14
12
10
8
6
4
2
0
I
II
III
IV
SEASON
Upper Greensand
Gault
Lower Greensand
18
Delayed flow - open symbol
Quick flow - closed symbol
SEASON

Fig. 7ix

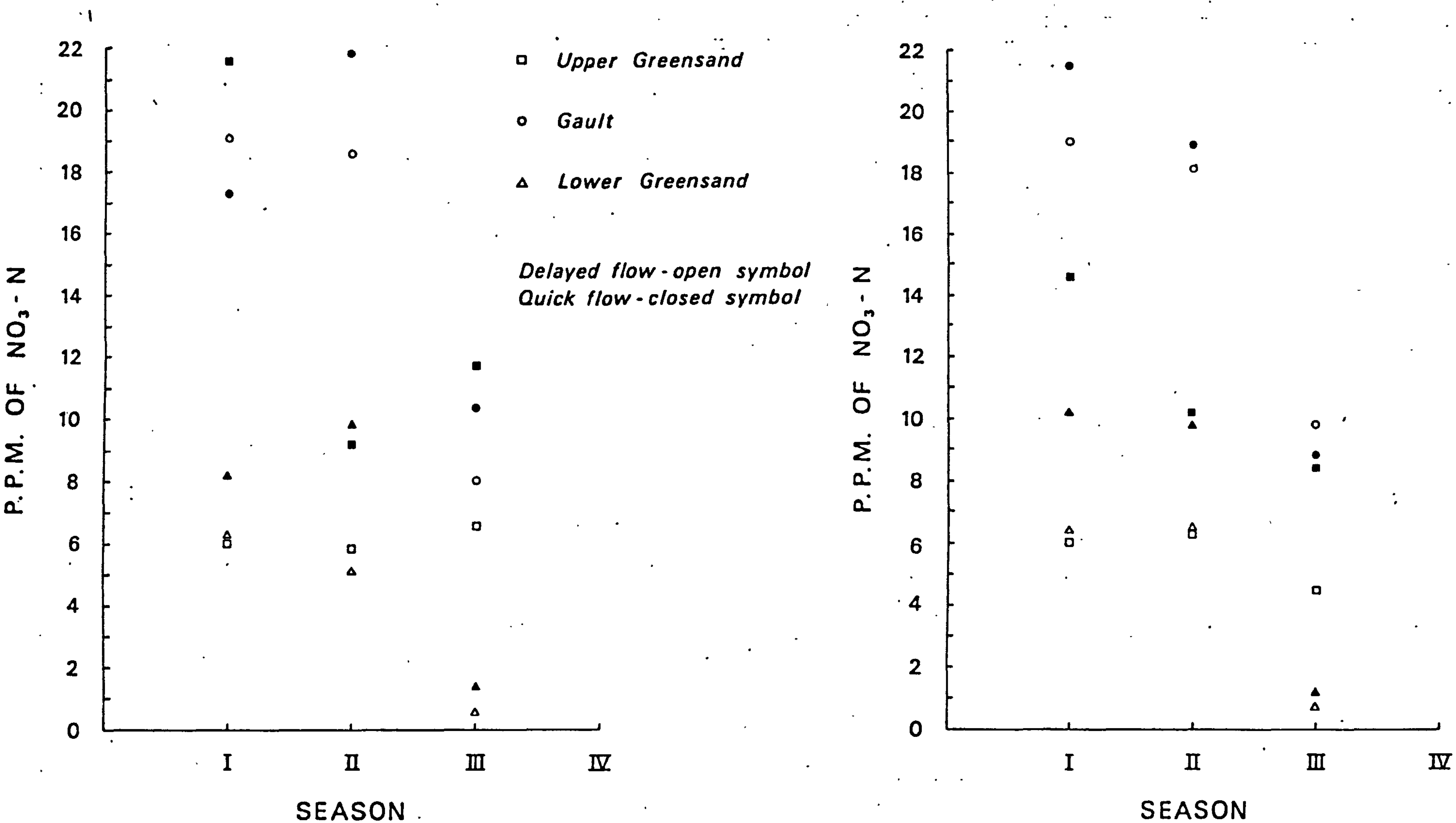
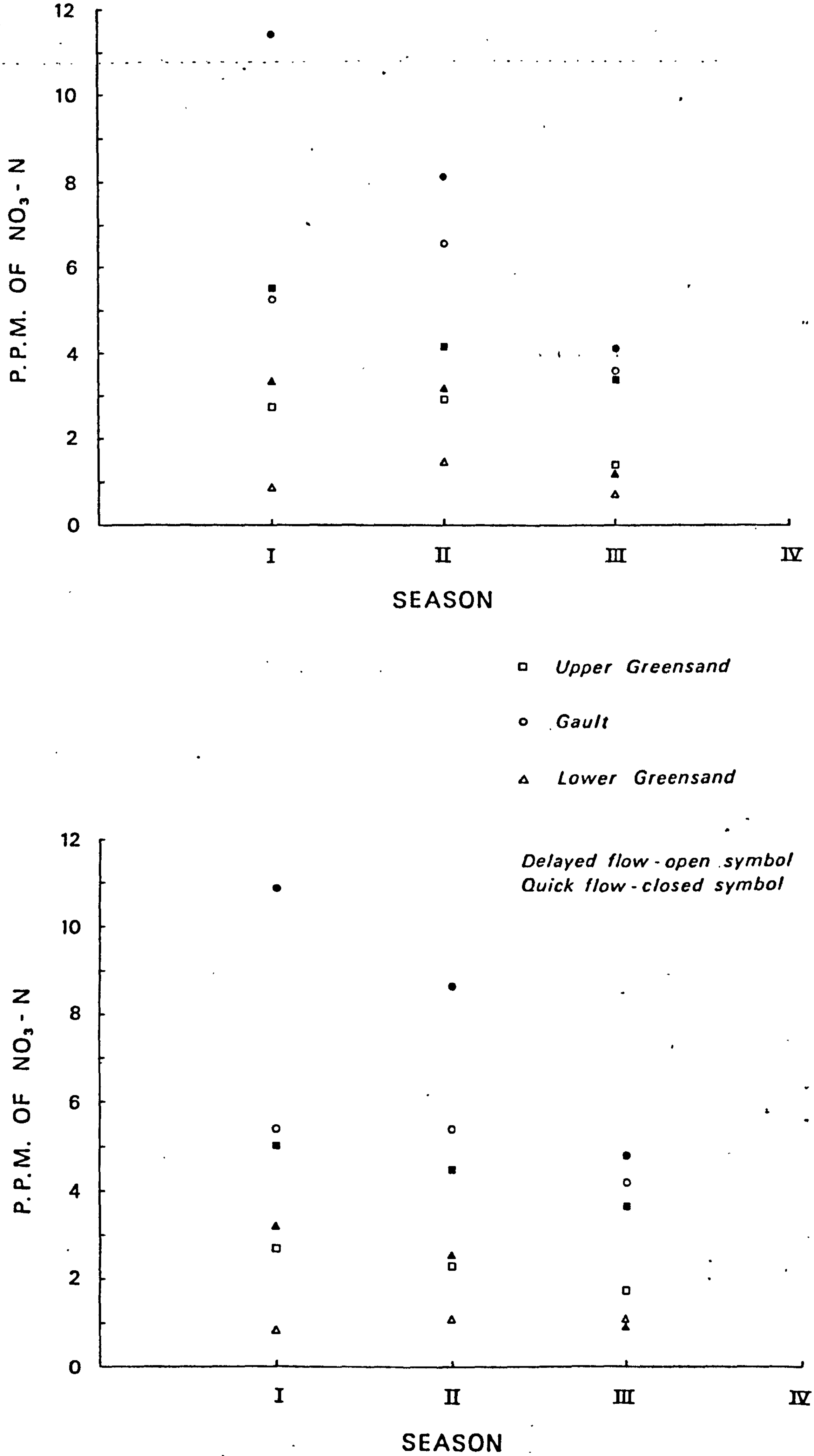

P.P.M. OF NO_3 - N
22
20
18
16
14
12
10
8
6
4
2
0
I
II
III
IV
SEASON
Upper Greensand
Gault
Lower Greensand
Delayed flow - open symbol
Quick flow - closed symbol
P.P.M. OF NO_3 - N
22
20
18
16
14
12
10
8
6
4
2
0
I
II
III
IV
SEASON

Fig. 7x


12
10
8
6
4
2
0
P.P.M. OF NO_3 - N
I
II
III
IV
SEASON
Upper Greensand
Gault
Lower Greensand
12
10
8
6
4
2
0
P.P.M. OF NO_3 - N
Delayed flow - open symbol
Quick flow - closed symbol
I
II
III
IV
SEASON

in field drains; all spring water was at one time soil water. The differences are probably due to the different hydrological behaviour of deep ground water systems and of shallow artificial soil drainage systems. The storage effect of ground waters could explain the absence of relations with discharge and season. Perennial springs on each lithology are undoubtedly fed by large groundwater bodies, in particular from the Chalk and Lower Greensand. Discharge changes are not marked in comparison to field drainage systems and therefore this effect will be masked. It is also possible that mixing takes place within groundwater systems so that throughputs from soil systems represents a set of hydrological events through time, thus reducing the effect of hydrological and seasonal changes.

Seasonal changes of flow in springs are relatively small (table 7iii). Large groundwater bodies, such as in the Chalk and Lower Greensand, produce lag effects of the order of a month, producing higher flows in the summer and lower flows in winter than areas with no ground water effects (Sussex River Authority, 1968).

Nitrate concentrations in springs increase in the order; Chalk, Lower Greensand, Upper Greensand. Upper Greensand springs display consistently higher concentrations as a group, than both others, and under both considerations of flow. The data used in the analysis of variance suggest some changing relationship between concentrations in Lower Greensand and Chalk springs from the first two to the last two seasons. The graphed data (Fig. 7i), however, show that the analysis of variance sample differs from the whole data set in this

TABLE 7 ii

SUMMARY OF DUNCAN'S MULTIPLE RANGE TEST ON MEAN NO_3-N VALUES FROM SPRINGS.

Annual Means:

$$\mu_c > \mu_l > \mu_u$$

Seasonal Means:

season I	$\mu_c > \mu_l$,	$\mu_c > \mu_u$
season II	$\mu_c > \mu_l$,	$\mu_c > \mu_u$
season III	$\mu_c > \mu_u$,	$\mu_l > \mu_u$
season IV	$\mu_c > \mu_u$,	$\mu_l > \mu_u$

The inequalities are significant at the 10% level.

μ_c : mean NO_3-N concentration in Chalk springs.

μ_l : mean NO_3-N concentration in Lower Greensand springs.

μ_u : mean NO_3-N concentration in Upper Greensand springs.

MEAN VALUES OF NITRATE NITROGEN CONCENTRATIONS IN SPRINGS

	seasonal means				overall mean
	I	II	III		
Chalk	2.6	3.2	2.6	2.5	2.7
Lower Greensand	4.1	4.2	2.9	2.7	3.5
Upper Greensand	5.1	4.6	5.3	4.8	5.0

respect. It seems more appropriate from the latter to suggest that concentrations in springs from Lower Greensand and Chalk do not differ a great deal at any season. Considering the plot of means for the whole data set (Figs. 7ii and 7iii) no relations are apparent between Nitrate concentrations and discharge conditions or between groups controlled for geology, discharge and season.

A higher concentration of Nitrates would be expected in Chalk springs in view of the high clay size content of its soils, (table 5i). Independent observations of Nitrates in drainage from Chalk soils in lysimeters (D. Harding, personal communication) show concentrations in the range 20 - 40 p.p.m. NO_3-N. Very high concentrations have been recorded in Chalk springs near Eastbourne, even over 50 p.p.m. NO_3-N (Green and Walker 1970). Although the authors attribute this to heavy fertilisation it remains clear that Chalk soils can yield high Nitrate concentrations in drainage water.

This disparity in the relative magnitude of Nitrate concentrations and the soil parameters seems contrary to the assumptions of Part 5. However, it is interesting to note (see below) that by far the most important parameter in explaining the variance of concentrations in field drainage is the presence or absence of arable enterprises. As stated, no single land use characteristic can be attributed to individual springs but the overall percentage areas in arable usage and the mean Nitrate concentrations are:

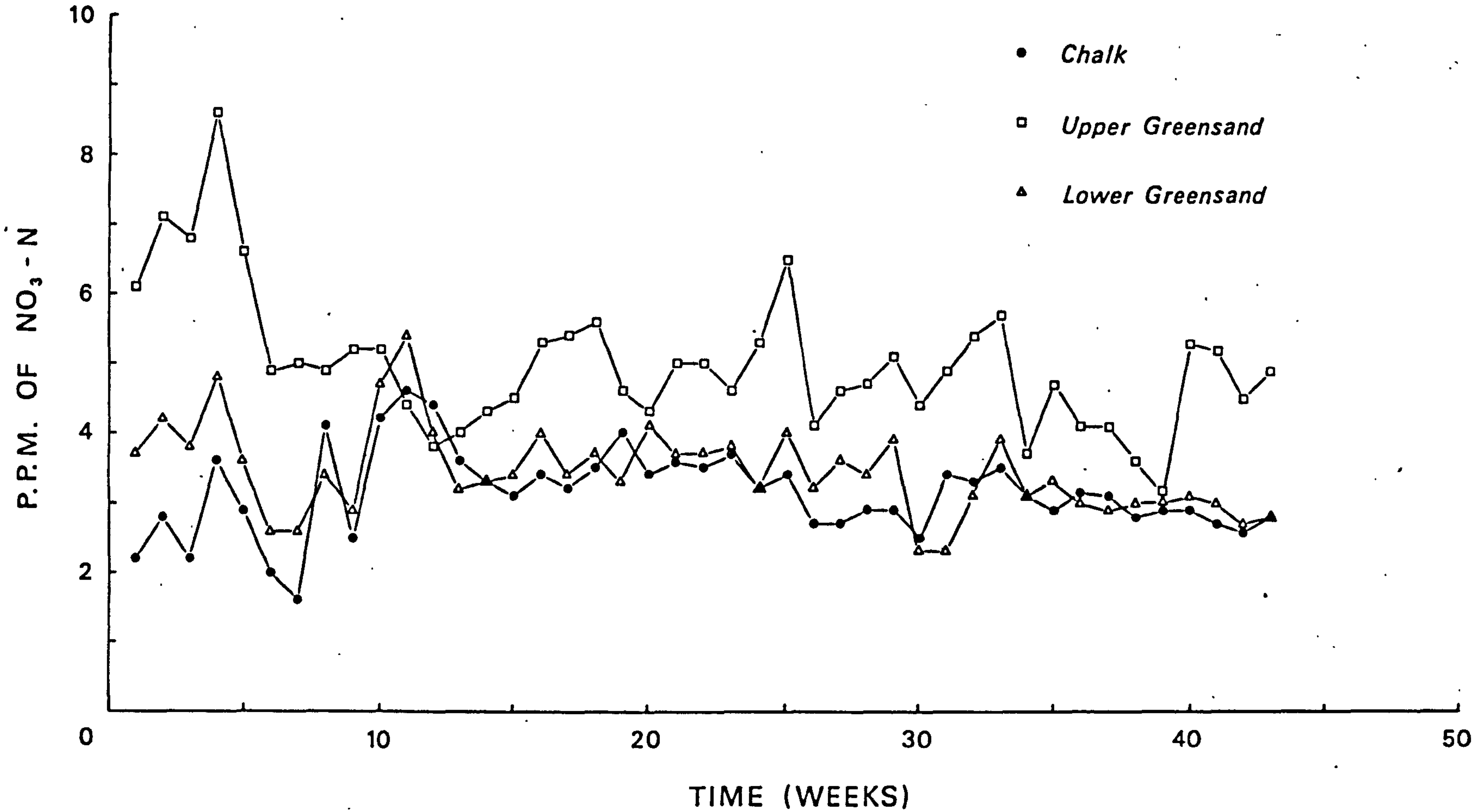


Fig. 7xi Mean weekly values of Nitrate Nitrogen concentrations observed in springs from different geological divisions.

	% Arable	Mean NO_3-N ppm.
Chalk	16	3.14
Upper Greensand	28	4.78
Lower Greensand	17	2.83

There is a close corresopndence between the relative magnitude of these two sets of figures. Thus, overall, springs from Upper Greensand are affected to the greatest extent by water which has derived from arable areas and springs from Chalk and Lower Greensand to a much less but similar degree.

The suggestion is that , even for spring drainage, Land -use must be considered an important factor controlling Nitrate concentrations. However there is no information which will allow this point to be investigated further.

FIELD DRAINS

Some combination of all four factors can be ascribed to each observation of Nitrates in field drainage samples. Therefore, a four way analysis of variance was performed on the sample data and the results are summarised in Tables 7 iv and 7 v.

Only three geological divisions support field drainage systems; none was found on the Chalk. The analysis shows that all four factors explain significant amounts of the variance at the 1% level. In addition there is a significant interaction between Land-use and geology, ie. the effect of Land-use practices on Nitrate concentrations varies according to the geology of a site.

TABLE 7iv

SUMMARY OF ANALYSIS OF VARIANCE ON NO_3-N VALUES FROM FIELD DRAINS

Effect	SS	Df	Ms	F	
Geology G	1743.5	2	871.8	33.1	%exp. - 21%
Land Use L	1890.8	1	1890.8	71.9	%exp. - 46%
Season S	690.9	2	345.4	13.1	%exp. - 8%
Discharge D	417.0	1	417.0	15.8	%exp. - 10%
Interaction G-L	260.5	2	130.2	4.9	%exp. - 3%
Interaction G-S	302.3	4	75.6		n. s.
Interaction G-D	94.6	2	47.3		n. s.
Interaction L-S	145.7	2	72.8		n. s.
Interaction L-D	39.7	1	39.7		n. s.
Interaction D-S	57.1	2	28.5		n. s.
Interaction G-L-S	159.8	4	39.9		n. s.
Interaction G-L-D	107.1	2	53.1		n. s.
Interaction L-D-S	1.8	2	0.9		n. s.
Interaction G-D-S	98.8	4	24.7		n. s.
Interaction G-L-S-D	175.7	4	43.9		n. s.
Residual	3792.8	144	26.3		
Total		179	4108.5		

/continued

TABLE 7iv. continued

Analysis of Variance Controlling the Effects of Land Use:

A: Arable Sites

Effect	SS	Df	Ms	F	
Geology G	1665.1	2	832.1	19.1	%exp. - 44%
Season S	735.6	2	367.8	8.4	%exp. - 20%
Discharge D	357.2	1	357.2	8.2	%exp. - 19%
Interaction G-S	424.9	4	106.2		n.s.
Interaction G-D	196.4	2	98.2		n.s.
Interaction S-D	23.2	2	11.6		n.s.
Interaction G-S-D	256.5	4	64.1		n.s.
Residual	3125.7	72	43.4		
Total		89	1871.8		

B: Non-Arable Sites

Effect	SS	Df	Ms	F	
Geology G	338.9	2	169.4	24.9	%exp. - 47%
Season S	101.5	2	50.5	7.4	%exp. - 14%
Discharge D	99.6	1	99.6	14.6	%exp. - 28%
Interaction G-S	35.2	4	8.8		n.s.
Interaction G-D	5.3	2	2.6		n.s.
Interaction S-D	35.6	2	17.8		n.s.
Interaction G-S-D	20.3	4	5.0		n.s.
Residual	490.8	72	6.8		
Total		89	360.8		

/continued

TABLE 7iv. continued

Analysis of Variance Controlling the Effects of Geology:

A: Upper Greensand

Effect	SS	Df	Ms	F	
Land Use L	694.9	1	694.9	21.1	%exp. - 39%
Season S	144.4	2	72.2		n. s.
Dircharge D	389.1	1	389.1	11.8	%exp. - 22%
Interaction L-S	76.5	2	38.2		n. s.
Interaction L-D	128.5	1	128.5		n. s.
Interaction S-D	135.5	2	67.7		n. s.
Interaction L-S-D	91.5	2	45.7		n. s.
Residual	1578.5	48	32.8		
Total		59	1764.5		

B: Gault

Effect	SS	Df	Ms	F	
Land Use L	1284.3	1	1284.3	33.6	%exp. - 70%
Season S	656.6	2	328.3	8.6	%exp. - 18%
Discharge D	57.6	1	57.6		n. s.
Interaction L-S	146.0	2	73.0		n. s.
Interaction L-D	8.2	1	8.2		n. s.
Interaction S-D	3.4	2	1.7		n. s.
Interaction L-S-D	81.7	2	40.8		n. s.
Residual	1837.5	48	38.2		
Total		59	1832.3		

/continued

TABLE 7iv continued

C: Lower Greensand

Effect	SS	Df	Ms	F	
Land Use L	172.0	1	172.0	41.9	%exp. - 41%
Season S	192.2	2	96.1	23.0	%exp. - 23%
Discharge D	64.9	1	64.9	15.5	%exp. - 16%
Interaction L-S	83.0	2	41.0	9.8	%exp. - 10%
Interaction L-D	4.9	1	4.9		n. s.
Interaction S-D	16.9	2	8.5		n. s.
Interaction L-S-D	9.6	2	4.8		n. s.
Residual	200.5	48	4.1		
Total		59	416.5		

n. s. = not significant at the 10% level

TABLE 7 v

RESULTS OF DUNCAN'S MULTIPLE RANGE TEST ON MEAN VALUES FOR FIELD DRAINS.

Geology effect:

$$\mu_G > \mu_U > \mu_L$$

Land-use effect:

$$\mu_A > \mu_{NA}$$

Season effect:

$$\mu_I > \mu_{III}$$

$$\mu_{II} > \mu_{III}$$

Discharge effect:

$$\mu_Q > \mu_D$$

Controlling for Land Use:

Arable

Geology effect:

$$\mu_{GA} > \mu_{UA} > \mu_{LA}$$

Season effect:

$$\mu_{AI} > \mu_{AIII}$$

$$\mu_{AII} > \mu_{AIII}$$

Discharge effect:

$$\mu_{AQ} > \mu_{AD}$$

Non-arable

Geology effect:

$$\mu_{GNA} > \mu_{UNA}$$

Season effect:

$$\mu_{NAI} > \mu_{NAIII}$$

$$\mu_{NAII} > \mu_{NAIII}$$

Discharge effect:

$$\mu_{NAQ} > \mu_{NAD}$$

Key to symbols

U	=	Upper Greensand.
G	=	Gault.
L	=	Lower Greensand.
A	=	Arable .
NA	=	Non-arable.
I	=	Season I .
II	=	Season II .
III	=	Season III .
D	=	Delayed flow.
Q	=	Quickflow.

The single most important factor is Land-use, ie the presence or absence of arable enterprises. This accounts for 46% of the variance and explains more than the other three factors combined. Geological differences account for 21% of the variance and geology and land-use together, with their interactions account for 70% of the total variance.

Unlike for springs the effect of Land-use and geology on field drains can be separated. For each geological type, through the three seasons when flows were observed for both states of discharge, arable areas yield higher concentrations of Nitrates then non-arable areas (Table 7 vi). For each outcrop geology, land-use remains the single most important factor accounting for 70% of the variance on Gault areas. The largest difference between different groupings of drains are between those on arable and non-arable. In general concentrations in drains from arable sites are between two and three times those from non-arable. There are only small departures from this range even controlling for all of the factors.

The highest mean concentrations are found in field drains from Gault, 8.50 ppm NO_3-N. Those from the Upper Greensand have an average concentration of 7.17 ppm NO_3-N and those from the Lower Greensand, 3.10 ppm NO_3-N. This order of magnitude corresponds with the order of the clay size contents:

	UGS	LGS	Gault
% organic	0.32	0.20	0.55
% clay	30.0	6.00	60.0

MEAN VALUES OF NITRATE NITROGEN CONCENTRATIONS (p.p.m.) IN FIELD DRAINS.

	seasonal			overall
	I	II	III	mean
Arable sites	13.0	11.8	6.4	10.4
non Arable sites	4.9	4.4	2.4	3.9
Quickflow Events	11.2	9.4	5.4	8.6
Delayed Flow Events	6.7	6.7	3.5	5.6
Gault	13.2	13.7	6.5	11.1
Upper Greensand	9.0	5.6	5.8	6.8
Lower Greensand	4.7	4.9	1.0	3.5
Seasonal Means	8.6	8.1	4.4	

	arable sites	non arable sites
Gault	15.8	6.5
Upper Greensand	10.2	3.3
Lower Greensand	5.4	1.8

Geology	land use	discharge conditions	I	II	III
Gault	arable	delayed	19.01	18.98	8.00
		quick	17,02	21.9	10.22
	non arable	delayed	5.36	6.52	3.62
		quick	11.46	8.08	4.06
Upper Green-sand	arable	delayed	6.00	5.95	6.48
		quick	21.64	9.34	11.72
	non arable	delayed	2.68	2.82	1.50.
		quick	5.60	4.18	3.54
Lower Green-sand	arable	delayed	6.10	5.04	0.60
		quick	8.25	9.94	1.50
	non arable	delayed	0.90	1.62	0.78
		quick	3.46	3.16	1.20

This order is maintained when controlling for Land-use and discharge. During the first season, although the analysis of variance data sample show concentrations in drains from the Gault to be significantly higher than those from the Upper Greensand the whole data set shows similar concentrations. During seasons II and III concentrations are higher in drains from the former. The lack of difference in the first season is attributed to flushing, an effect which is most evident at sites on the Upper Greensand The highest weekly concentrations at these sites were during the first few weeks of observed flow (see Appendix 2 and Fig. 7xii), several being over 30 ppm. NO_3-N.

The effect has been noted by several authors and is probably due to the accumulation of material in the soil and the ground surface during dry periods. The effect was most marked at sites on the Upper Greensand and raised the mean value of Nitrate concentrations for season I to a level similar to those of the Gault.

Nitrate concentrations are higher during wetter conditions (Table 7 vi) . When the effect of geological differences is controlled for, the relation does not hold for drains from the Gault. The whole data set for the Gault is similar to the analysis of variance sample in showing no significant difference between concentrations under both discharge states at each season. For drains from the site on Gault when the effect of land-use is controlled it is found that the non-arable drains experience higher concentrations during wetter periods but only during the winter, season I. Otherwise differences are not significant.

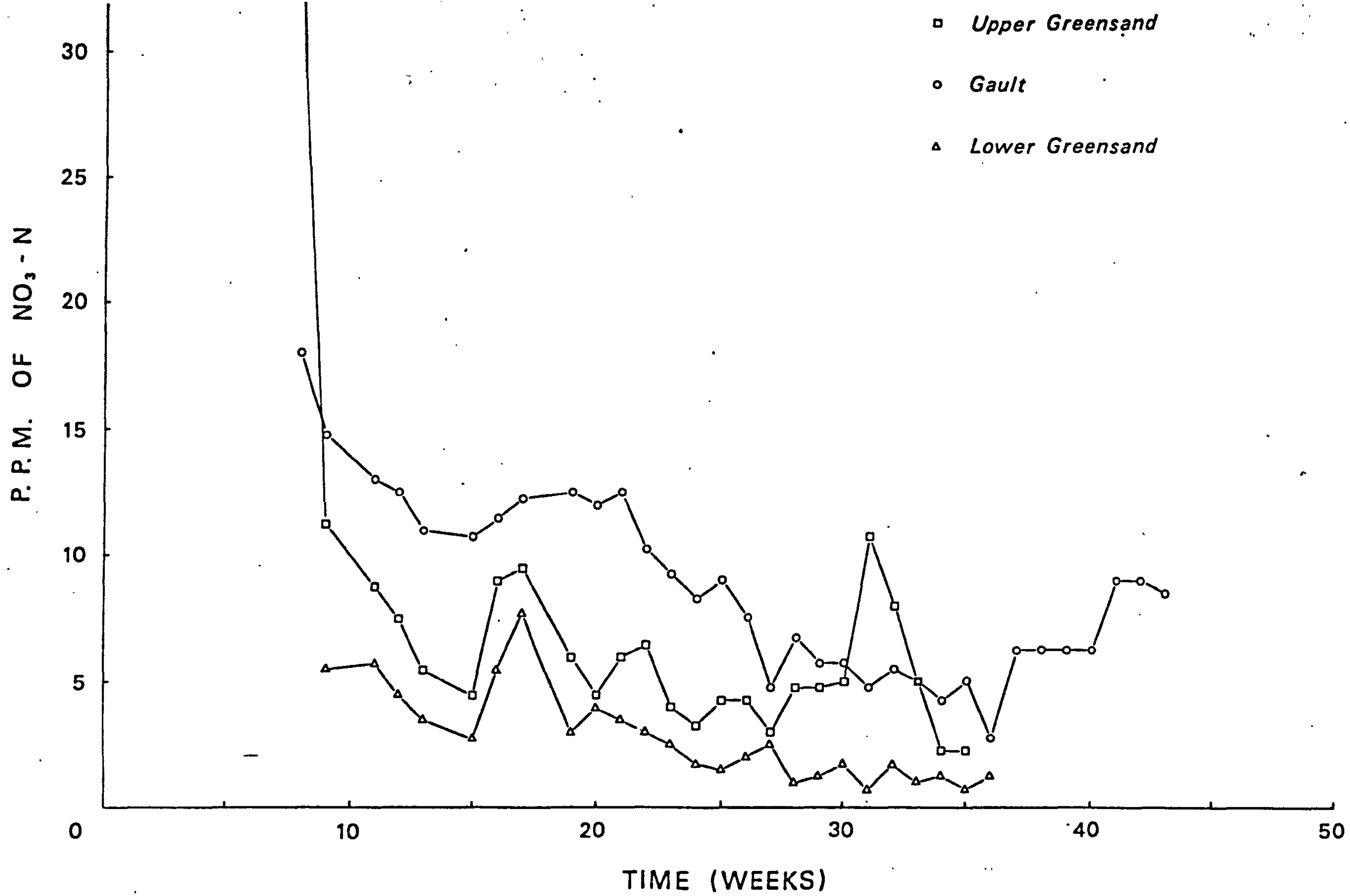


Fig. 7xii Mean weekly values of Nitrate Nitrogen concentration observed in field drains from different geological divisions.

The overall lack of difference is attributed to the hydrological properties of clay soils, not allowing throughflow to the same degree as lighter soils.

The greatest effects of discharge are during season I and they are especially large at arable sites. This is the period after a long dry summer and autumn harvest when soils probably had relatively high Nitrate concentrations and the soil temperature had not fallen too low for mineralisation to be prevented. It is also during season I that the largest discharge events took place (Fig. 2 iii).

The relatively low concentrations during wet periods in season III are attributed to the small size of the rainfall events and the overall lack of soil moisture during early summer restricting its effectiveness in the leaching process.

Under non -arable conditions with no discharge effects the conclusions from part 5 would be that available soil Nitrogen would change little during the year. A spring rise in soil Nitrogen would be reflected in drainage water if leaching did not occur. For non-arable sites under dry conditions for each geological type there are no significant differences in Nitrate concentration of drainage water from season to season which accords with this interpretation.

Marked seasonal changes in Nitrate concentration occur in drains from arable land and from non-arable land under quickflow conditions. It is difficult to compare the wet parts of the different seasons because of the different magnitudes of hydrological events which they represent. Season I experienced the largest, season III the smallest. The mean Nitrate concentrations follow this pattern (Table 7 vi). No drains were observed to flow in season IV.

The larges seasonal change is from season II to season III .

Although season III is the season when temperatures are relatively high, net mineralisation rates will diminish as plant growth occurs. This is also a time of high evaporation and consequently of low soil moisture which implies low potential for leaching. During season III all the field drains ceased to flow.

Controlling for discharge conditions the differences between arable and non-arable sites for each geology are reduced significantly from period II but do not alter significantly from period I to II. This is interpreted as being due to the effect of plant growth on soil Nitrogen .

The effects of sampling the whole data set for groups of only five observations makes more detailed analysis risky as there are some discrepancies between their patterns of change and the changes of the whole data set.

SUMMARY.

The four factors which form the basic inputs to a simulation model explain high proportions of the variances of Nitrate concentrations in a set of samples from field drains and springs. The differences between group means correspond to those that would be expected from the arguments presented in part 5. Therefore it is concluded that the physical basis of the model is justified.

PERIODS OF FLOW.

The effects of field drains and springs on Nitrate concentrations in rivers depends in part on their concentration of Nitrates and in part upon the volumes of their flow. No measurements were made of discharge sources. However, it is useful to consider their period of flow in order to assess when these sources are potential major contributors of Nitrate to the river.

Periods of flow depend to a large extent on the rainfall during a year and this prevents any general statements about this variable, especially as the study year was a dry one, but it is possible to make comparitive statements.

Upper Greensand and Lower Greensand did not support drains which flowed for more than 28 weeks of the study period. Gault did not support any which flowed for more than 35 weeks. During the periods when the selected drains did not flow, no other drains were observed to do so. The periods of flow are shown in Appendix 2; the averages are:

Upper Greensand	17 weeks
Gault	29 weeks
Lower Greensand	17 weeks

Drains from Gault flow for significantly longer periods than from the other geologies. Heavy clay soils are much less permeable than loams and sandy soils (Marshall, 1959, p. 30, indicates an order of magnitude difference)*, and therefore will produce more quickflow after rain. The fact that flow is sustained for longer periods is attributed to their slow draining. The general relation between conductivity and soil suction (after Hillel, 1970) is presented in Fig. 7 xiii. Under similar conditions this implies that the comparative time changes of flow are as in Fig. 7 xiv.

Chalk, Upper Greensand, and Lower Greensand supported springs which flowed throughout the period of observation. Those from the Upper Greensand flowed for a shorter period than either Chalk or Lower Greensand. Their average periods of flow during the study were:

Chalk	45 weeks.
Upper Greensand	34 weeks.
Lower Greensand	41 weeks.

Assuming that the size of the groundwater body feeding springs is proportional to the size of the topographical features formed by each lithology then the Upper Greensand, forming a bench in front of the Chalk escarpment, has the smallest groundwater body. This probably accounts for the shorter average period of flow of the Upper Greensand springs.

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* Horizontal Hydraulic Conductivity (saturated):

Fine sand	5.8×10^{-3}	cm/sec.
Sand loam	1.6×10^{-3}	..
Clay	1.1×10^{-4}	..

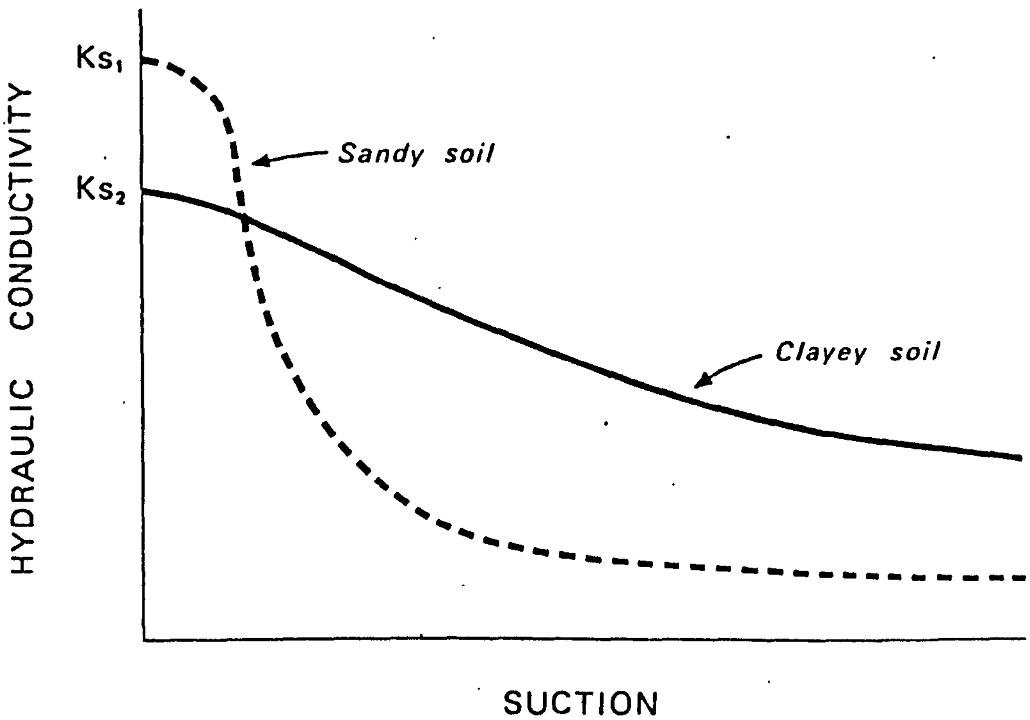

Fig. 7xiii Hypothetical relations between soil conductivity and soil suction for different soil types.

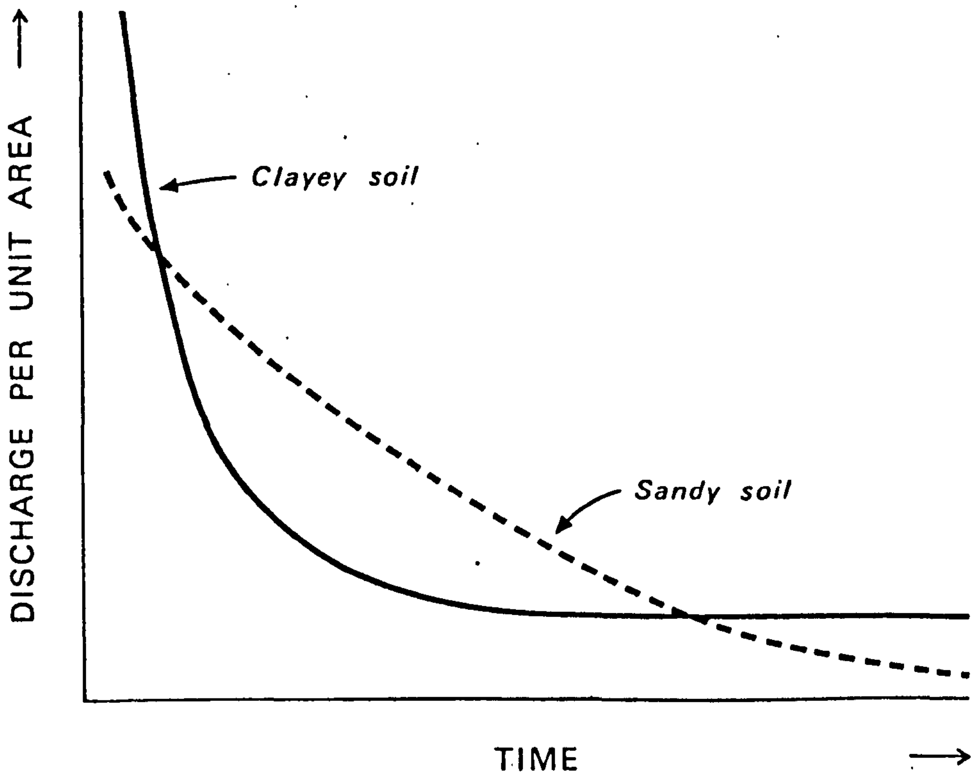

Fig. 7xiv Hypothetical time changes of flow rate from different soil types.

PART 8

SEWAGE WORKS

The NO_3-N concentrations in the river and its tributaries depend not only upon the flow from the springs and field drains but also from sewage works. It is necessary to consider their behaviour before hypothesising the values to be found.

The largest point sources of nitrates to the river are the five sewage works of the area at Buriton, South Harting, Rogate, Liss and Petersfield. The First Periodic Survey of the Sussex River Authority (1968) lists their dry weather discharges as follows:

	M^3/day
Petersfield	1980
Liss	1210
South Harting	170
Rogate	115
Buriton	95

These discharges can be expected to be higher during 1972-3 because of the increase in population and per capita consumption of water. Continuous monitoring at the Petersfield works during 1972-3 show a dry weather flow of approximately 6000,000 galls/day, equivalent to 2740 M^3/day. This is an increase in the ratio 1:1.38 . Assuming similar changes for each works the dry weather flows during the period of study would be:

	M^3/day
Petersfield	2740
Liss	1670
South Harting	234
Rogate	158
Buriton	131

There are no large industrial inputs to these works although effluent from an abattoir is received at Petersfield, and from three farms at South Harting. All these works use percolating filter beds and settling tanks. Nitrogen is converted into the Nitrate form through bacteriological action. The effectiveness of the process depends on the activity of the bacteria which is strongly controlled by temperature. Thus during warmer weather higher Nitrate concentrations are found in the effluent from this type of works (see Appendix 2). Lower concentrations are found in the newer, more efficient works. Petersfield works is newer and has consistently lower concentrations in its effluent than the older (pre-war) works at Liss. The effluent from the older works generally contains higher Ammoniacal Nitrogen concentrations and more suspended solids. The effect of these on Nitrate Nitrogen concentrations in rivers is difficult to assess. In the Rother, where the effluent load on the main stream is not large, oxidising conditions prevail. The total effluent load is of the order of 0.10 cumecs (Water for Sussex, 1968) whereas the expected summer baseflow is 2.2 cumecs for the whole Rother basin (area 470 sq km.). Above Iping (area 153 sq km.) total flow equivalent of effluent is, according to 1963 data, 0.045 cumecs. The dry weather flow of the Rother at Iping is approximately 0.7cumecs, fifteen times larger. If the effluent load is assumed to have increased by a factor of 1.38 the flow equivalent would be 0.062 cumecs, one eleventh of the expected low flow at Iping.

There is a possibility that the Nitrate load of the river will be increased by the oxidation of the effluent material after entering the river. There is no data to test this effect. However, the concentrations of Ammoniacal Nitrogen in the sewage effluents during the study was generally less than 1 ppm. (approximately 5% of the Nitrate Nitrogen load) during low flow. If it is assumed that suspended solids contain 5% Nitrogen and constitute 50 ppm. of the effluent, then the concentration of Nitrogen is 2.5 ppm. or approximately 12.5% of the total concentration of Nitrate Nitrogen. If this is totally converted to Nitrate in the river then the effect on the concentrations in a river where 50% of the load comes from sewage works and the expected concentration is 5 ppm., will be 0.3ppm. Thus, even in the unlikely event of all of the largest possible load of Nitrogen being converted to Nitrate in the river the net effect is relatively small.

Nitrate concentrations in the effluent are seriously affected by management practices. If filter beds become clogged or poisoned or settling tanks fail to operate efficiently there is a tendency for NH_4 - N and suspended solids concentration to rise and NO_3-N concentration to fall*. Such effects are generally short-lived. The River Authority maintained regular inspection of the works and samples were taken frequently to enforce the Royal Commission standards.

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*Such an occasion was March 21st 1973: NO_3- levels fell at Petersfield while rising at Liss from the previous week. NH_4-N concentrations increased from negligible to 4.0ppm.

Concentrations of Nitrate in the effluent are not observed to be affected by influent load. No discernible patterns of concentration were observed during the 24 hr cycle of operation (Appendix 3). When the influent is affected by storm flows however, there can be very large changes in the Nitrate concentration in the effluent. Storm water systems are often routed to sewage systems and provide a greatly increased flow during wet weather which greatly dilutes influents. Most works are provided with overflow tanks but these occasionally fail and wastes flow directly through the works without treatment. In these circumstances wastes are very dilute in Nitrates.

Flows from the works at Petersfield are monitored continuously and therefore it is possible to make estimates of the flow from the other works. Estimates are made using total daily flows at the Petersfield works, Q_p ; other works are assumed to discharge a constant proportion of the effluent at Petersfield. The proportions are, on the basis of dry weather discharges:

Petersfield	1.00
Liss	0.61
South Harting	0.08
Rogate	0.05
Buriton	0.04

It is assumed that the two main variables affecting Nitrate concentration in sewage effluent at a particular works are air temperature and discharge at the works. The data from Liss and Petersfield allow a distinction to be made between the older and newer works.

A model of Nitrate concentrations (N_i) expressing these relations has been constructed, based on 9.00 am screen temperatures at Rogate (T) and mean daily flows at Iping (Q_I). It takes the form:

$$\text{Log } N_i = aT + b \log Q_I$$

A multiple regression procedure was used, employing a WANG desk top computer. The analysis is presented in Table 8 i. For the Petersfield works Nitrate concentrations the adjusted multiple correlation coefficient is 0.847, ie. 71% of the variance is explained by these two variables. The dominant variable is discharge, alone it explains 59% of the variance. Discharge and temperature are probably not independent variables and so it is not possible to apportion variances.

The same model for the Liss effluent data yields a multiple correlation coefficient of 0.763, ie. 58% of the variance is explained. However, the dominant variable here is temperature, though alone it explains only 43% of the variance in nitrate concentrations.

As estimates of flow from works other than Petersfield are not available they have been made on the basis of a constant proportion of those at Petersfield.

The behaviour of the works varies somewhat in terms of NO_3- N values. A suitable general model is not likely to be based on available information. Therefore, in the analysis which follows values relating to the Liss and Petersfield works are used as estimates of values at the others. The works at Petersfield and

TABLE 8 i

SUMMARY OF REGRESSION OF NITRATE CONCENTRATIONS AT LISS AND PETERSFIELD SEWAGE WORKS ON TEMPERATURE AND DISCHARGE VALUES.

variable 1.	Mean Weekly Temperature, Rogate
2.	Log Daily Discharge, Iping Weir
3.	NO_3-N Concentration - Liss Works
4.	NO_3-N Concentration - Petersfield Works

LISS

Reduced sum of squares	0.5928
Multiple Correlation	0.763
F Value	27.67

variable	Regression Coefficient	T Value
1	0.0172	4.95
2	-0.2188	-3.53

Intercept 1.3427

PETERSFIELD

Reduced sum of squares	0.7234
Multiple Correlation	0.8469
F Value	49.93

variable	Regression Coefficient	T Value
1	0.0121	4.21
2	-0.3658	-7.16

Intercept 1.4048

Buriton, which are of recent construction are assumed to behave similarly, as are those at Liss, Rogate and South Harting, which are of older construction.

PROGNOSIS

During the year, because of changes in flow and concentration there are changes in the relative importance of the various sources contributing to the Nitrate load of the river. It is postulated that the pattern of change of Nitrate in the main river system will correspond to these changes in the following way:

1. In the upper stretches of the tributaries, which derive from the Chalk, the Nitrate concentrations will remain relatively constant throughout the year in the range 2 - 4 ppm.

2. Where tributaries cross the Upper Greensand, which generally supports a high percentage of arable land use, concentrations of Nitrate will rise. During the drier parts of the year this rise will be small because of the absence of field drainage. In the wetter parts of the year the rise will be very substantial, particularly in the first wet periods after long dry spells.

3. Where the Gault supports relatively large areas of arable land there will continue to be a rise in the Nitrate concentrations as the tributaries cross this outcrop. Otherwise changes will be relatively small. Because the effect of sources is largely inversely proportional to the

discharge in the river, the changes in crossing the Gault may not be as great as the relative difference in concentrations between drains on this and Upper Greensand.

4. As tributaries cross the Lower Greensand, concentrations will fall though, again, not in proportion to the relative concentration of Nitrates in the springs and field drains.

5. Changes in Nitrate concentrations in the river below sewage works will be greater in summer than for the same flows in winter.

6. During summer the downstream profiles of Nitrates will be smoother and lower than in winter except where sewage works are found, where the pattern will be reversed.

7. The major departures from generally low Nitrate concentrations will be due to the effects of:

a) land drainage from arable land on the Upper Greensand and Gault in wet periods, particularly in seasons I and II.

b) sewage works at all times of the year except during very high flows, but particularly during low flows in Seasons III and IV.

PART 9

ANALYSIS OF OBSERVATIONS OF RIVER NETWORK

Having tentatively established the relations between the factors and NO_3-N concentrations at the scale of springs and field drains and knowing the behaviour of the other major source of Nitrates, ie, sewage effluents, two problems remain:

i. what are the relations between the four factors and NO_3-N concentrations in the streams and the river?

ii. can the four factors be used to predict these NO_3-N values?

An examination of the downstream changes of NO_3-N concentration does not provide a suitable quantitative method of analysis but does allow some selectivity in examining the data.

Individual profiles show the effects of geology and Land-Use, and the presence of the major effluents. . These for the main river (Table 9 i) show the dominant effect of sewage effluents on the overall profile. The effect is more marked in the drier seasons, III and IV, though in fact the highest concentrations in the main river are found in the wetter seasons. That the effects appear to be shown only immediately downstream is probably due to the sampling time in relation to the downstream movement of effluent peaks and this in fact provided a reason for the time of sampling.

The profiles for the tributary streams show more marked features. Again some of the major changes are due to the presence of sewage works; on the Stanbridge Stream network at Buriton and on the Harting Stream at South Harting. Below these works (Table 9 ii). Seasons I and IV show the greatest downstream changes. Examination of the weekly values (Appendix 2) show this pattern more markedly

TABLE 9 i

SEASONAL MEAN VALUES OF NITRATE NITROGEN CONCENTRATION AT STATIONS ON THE MAIN RIVER.

Station	Seasonal Means				Delayed Flow-Means				Quickflow - Means				Overall mean.
	I	II	III	IV	I	II	III	IV	I	II	III	IV	
Main River													
1	2.24	1.98	1.82	0.98	2.04	1.85	1.32	0.93	2.47	2.40	3.47	1.60	1.75
2	4.32	3.28	3.42	4.66	3.90	3.09	3.40	4.70	4.82	3.93	3.47	4.20	3.92
3	3.02	2.76	2.57	2.26	2.80	2.63	2.33	2.25	3.28	3.20	3.37	2.40	2.65
4	4.26	3.44	3.68	3.35	4.39	3.38	3.54	3.35	4.12	3.63	4.13	3.30	3.68
5	3.96	3.18	3.12	2.68	3.73	2.95	2.85	2.66	4.23	3.93	4.00	2.90	3.23
6	5.03	3.90	4.27	4.58	5.11	3.80	4.16	4.67	4.93	4.23	4.63	3.40	4.44
7	4.42	3.75	3.40	3.12	4.07	3.58	3.12	3.08	4.82	4.33	4.33	3.60	3.67
8	4.81	3.81	3.57	3.17	4.49	3.67	3.38	3.14	5.18	4.37	4.20	3.50	3.84
9	5.14	3.83	3.79	3.71	4.96	3.69	3.61	3.69	5.35	4.30	4.40	3.90	4.12
10	5.07	3.91	3.62	3.35	4.77	3.75	3.40	3.32	5.42	4.43	4.37	3.70	3.99

TABLE 9 ii

SEASONAL MEAN VALUES OF NITRATE NITROGEN CONCENTRATION AT STATIONS ON TRIBUTARY STREAMS.

Station	Seasonal Means				Delayed Flow - Means				Quickflow - Means				Overall mean.
	I	II	III	IV	I	II	III	IV	I	II	III	IV	
Hammer Stream													
11	3.97	3.57	2.30	1.57	3.04	3.29	2.00	1.57	5.05	4.50	3.30	1.60	2.85
Batts Brook													
12	2.96	3.12	2.61	1.97	2.33	2.94	2.44	1.92	3.70	3.70	3.17	2.60	2.66
13	2.96	3.52	2.45	1.22	2.00	2.94	2.02	1.15	4.08	5.50	3.90	2.00	2.54
Coldhayes Stream													
14	3.31	4.59	3.68	3.13	2.39	4.53	3.62	3.07	4.38	4.80	3.87	3.80	6.40
15	9.14	7.56	5.27	3.65	3.70	6.34	4.50	3.51	15.48	11.63	7.83	5.30	6.40
16	7.39	6.21	3.85	1.85	3.17	4.99	3.06	1.75	12.32	10.27	6.50	3.00	4.82
Ashford Stream													
17	2.46	2.42	2.00	1.64	2.09	2.36	1.91	1.61	2.90	2.63	2.30	2.00	2.13
18	3.47	2.72	2.43	2.02	2.71	2.53	2.21	2.00	4.35	3.33	3.17	2.30	2.66
19	3.52	2.73	2.40	2.02	2.64	2.49	2.18	2.00	4.53	3.53	3.13	2.30	2.67
Tilmore Brook													
20	3.54	6.82	8.62	9.92	1.27	7.32	9.19	9.06	6.18	5.17	6.70	9.50	7.23
21	2.95	3.35	2.37	1.97	2.54	3.26	2.09	1.60	3.43	3.67	3.30	6.40	2.66
22	2.49	2.72	2.41	1.99	1.89	2.57	2.19	1.85	3.20	3.20	3.13	3.70	2.40
Stanbridge Stream													
23	2.08	2.92	1.92	1.21	1.47	2.92	1.82	1.11	2.80	2.93	2.27	2.40	2.03
24	4.45	4.20	2.78	1.59	1.99	3.71	2.03	1.44	7.32	5.83	5.30	3.40	3.26
25	4.00	3.88	2.43	1.52	1.49	3.44	2.00	1.35	6.93	5.37	3.87	3.60	2.96
26	6.53	4.16	3.82	5.45	6.34	3.86	3.66	5.61	6.75	5.17	4.35	3.50	4.99

/ cont.

TABLE 9 ii cont.

Crundle Stream	I	II	III	IV	I	II	III	IV	I	II	III	IV	Overall mean
27	4.17	2.75	1.18	0.23	0.89	2.05	0.65	0.17	8.00	5.10	2.93	1.00	2.08
28	3.13	2.73	2.22	1.78	2.30	2.55	1.96	1.70	4.10	3.33	3.07	2.80	2.47
29	3.38	2.65	1.38	0.55	1.93	2.37	1.15	0.52	5.08	3.60	2.17	1.00	1.99
30	4.41	2.72	1.48	1.02	3.01	2.41	1.27	1.01	6.03	3.77	2.17	1.30	2.41
Harting Stream													
31	2.88	2.87	1.98	1.24	1.90	2.79	1.88	1.20	4.03	3.13	2.33	1.70	2.24
32	7.09	4.82	6.70	8.61	8.69	4.93	6.98	8.88	5.23	4.47	5.77	3.30	6.81
33	6.40	4.18	5.25	7.68	7.10	4.31	5.61	7.95	5.85	3.77	4.03	4.50	5.88
34	6.72	4.29	5.65	6.69	7.90	4.42	6.02	6.84	5.33	3.87	4.40	4.90	5.84
Dumpford Park Stream													
35	8.12	6.34	5.08	4.82	5.30	6.10	5.05	4.68	11.42	7.13	5.17	6.40	6.09
Goldrings Stream													
36	11.11	10.68	9,47	8.54	10.36	9.97	9.85	8.52	11.98	13.07	8.20	8.80	9.95

which were periods of continued low flow.

Other noticable effects are associated with sites below areas underlain by Gault. In particular along Coldhays Stream (Table 9 ii) These effects are most marked in periods I and II, though weekly values show no effect during the first few weeks of season I (Appendix 2). A similar pattern is shown in the Stanbridge Stream above the A3 station and along the Ashford Stream below stations at Roke and Harrow. In the latter the effect is much less marked but the basin is not dominated by Gault to the same extent as for the other streams.

Batt's Brook basin between Barefoots and the A325 is underlain predominantly by Gault but very little is arable land-use and there are no significant downstream changes (Table 9 ii & Table 9 iii). Concentration changes along the Crundle Stream seem to possess other relations. The most marked increases in concentration are during seasons III and IV along a stretch draining predominantly Upper Greensand and the most marked decreases are along a stretch draining predominantly Gault. There are no major changes during seasons I and II. These apparent anomalies can be explained by the patterns of land-use. The Upper Greensand above Goose Green is 42% in arable use and the reach in between contains a lake which acts as a nutrient trap. Thus the concentrations decrease along the lower stretch even though it drains a large area of Gault. High concentrations above Torberry in seasons I and II are associated with high % land in arable use, 31%, on the lower Chalk. Thus

TABLE 9iii

	% areas underlain by:				% areas in arable use and underlain by:			
	Chalk	UGS	Gault	LGS	Chalk	UGS	Gault	LGS
1	5.2	17.4	27.8	54.6	2.1	3.6	2.7	1.1
2	18.9	40.6	36.7	1.8	0.7	7.6	4.5	
3			2.8	97.2			0.8	13.3
4	42.7	42.5	14.8		3.2	6.1	1.4	
5			82.5	17.5			20.0	1.9
6			0.1	99.9				5.8
7	9.6	46.7	43.8			2.7	3.9	
8		13.4	86.6				31.0	
9			8.5	91.5			7.2	1.4
10	73.6	26.4			12.6	1.7		
11		28.4	45.8	25.9		3.5	19.9	12.6
12				100.00				30.2
13			0.4	99.6				17.1
14	13.3	16.0	44.3	26.3			0.6	12.2
15		3.1	18.5	78.3			0.2	2.8
16	3.4	7.4	12.5	77.9		0.3		8.3
17	18.8	59.7	21.5		0.5	14.9		
18	30.5	27.4	36.1	3.9	3.2	8.2	1.3	2.5
19	35.3	27.7	21.6	15.4	4.1	6.5	0.6	1.6
20	21.0	53.0	22.1	3.8	0.4	19.7		
21				100.0				24.0
22	69.3	30.7			31.3	20.2		
23	16.0	80.4	3.6		9.1	42.4		
24		13.8	66.7	19.5		6.9	7.3	1.9
25		24.8	40.4	34.7		8.4	7.1	0.8
26				100.0				34.0
27	70.1	29.9			17.5	9.2		
28	27.5	60.4	12.1		15.9	18.0		
29	13.0	26.5	56.8	4.1	4.5	12.1	2.7	1.1

TABLE 9iii (cont.)

	% areas underlain by:				% areas in arable use and underlain by:			
	Chalk	UGS	Gault	LGS	Chalk	UGS	Gault	LGS
30			13.3	86.7				26.0
31				100.0				32.5
32	3.0	30.1	62.2	4.8	0.6	9.4	5.4	2.0
33			33.6	66.4			8.9	2.9
34				100.0				
35			*67.3	32.7				0.7
36				100.0				47.2

* Weald Clay

UGS Upper Greensand

LGS Lower Greensand

during seasons I and II there are no significant downstream differences in NO_3-N concentrations in the Crundle Stream.

Another anomaly is presented by the Tilmore Brook which shows an increasingly marked downstream change as the seasons progress. The uppermost part of the basin above Barelands is dominated by Gault but very little is in arable land use. This would explain a downstream decrease in concentration but not the unusual seasonal change. The site at Barelands however, is strongly affected by farm yard drainage and much higher concentrations of NO_3-N are found than would normally be the case and the effect increases during the seasons of low flow, ie. III and IV.

In general the downstream changes correspond to those expected from the previous analyses. The most distinct features are the importance of Gault areas and the sewage effluents, where they occur. Further they produce their most pronounced effects at different seasons. In the main river the most pronounced effect is from sewage works although the highest concentrations occur in winter months when land drainage is most effective. In the tributary stream the effects of the other factors can be discerned.

The data can also be considered as at-a-station time changes. On inspection a distinct set of patterns emerge of change in mean values. There are three distinct patterns of change:

1. a monotonic decrease from season I to IV.

2. a peak in season II.

3. peaks in season I and season IV.

Some stations do not exhibit any pattern which is recognised at other stations and these are put into a miscellaneous class, ie. 4.

The seasonal changes of mean values are presented in Table 9 iv, with significance based on paired t tests indicated in Table 9 v. Pattern 3 is associated with sites below sewage works. These are sites with higher concentrations during seasons I and IV and lower concentrations during seasons II and III. On Harting Stream, the three stations below Harting Sewage Works show this pattern as does the station, Stanbridge, below Buriton Sewage Works. On the main river, Durford, below Petersfield works shows pattern 3, however, below Liss works, at Prince's Bridge, this pattern is distorted for no discernible reason. Pattern 3 is also found at the Hawkley station suggesting that an effluent discharges into the river above. No account has been taken so far of any works nor have any of the analyses indicated its existence. In fact, a very small sewage plant does operate in the basin which serves the small community of Le Court.

The other patterns of change are more difficult to interpret. Overall the highest concentrations are found in season I. This is the season of the highest flow, when most fallow land is found and when there is a likelihood of flushing. Considering the patterns for the twenty eight sites not affected by sewage works only three, 28, 29 and 30, show a monotonic decrease (pattern I) from each station to the next which is ~~are~~ significant. However, if two seasonal means

TABLE 9 iv

PATTERNS OF TIME CHANGE OF SEASONAL VALUES OF NO_3-N CONCENTRATION.

Station	Pattern type No.	Pattern for delayed flow conditions	Dominant geological type immediately upstream.
1	1	1	L. G. S.
2	3	3	U. G. S.
3	1	1	L. G. S.
4	4	4	L. G. S.
5	1	1	L. G. S.
6	3	3	L. G. S.
7	1	1	L. G. S.
8	1	1	L. G. S.
9	1	3	L. G. S.
10	1	1	L. G. S.
11	1	2	W/Clay
12	2	2	Chalk
13	2	2	Gault
14	2	2	U. G. S.
15	1	2	Gault
16	1	2	Gault
17	1	2	Chalk
18	1	1	U. G. S.
19	1	1	L. G. S.
20	4	4	Gault
21	2	2	L. G. S.
22	2	2	L. G. S.
23	2	2	U. G. S.
24	1	2	
25	1	2	
26	3	3	U. G. S.
27	1	2	Chalk
28	1	2	U. G. S.
29	1	2	Gault
30	1	1	L. G. S.
31	2	2	Chalk
32	3	3	U. G. S
33	3	3	Gault
34	3	3	L. G. S.
35	1	2	Gault
36	1	1	L. G. S.

L. G. S. - Lower Greensand
U. G. S. - Upper Greensand
W/Clay - Weald Clay

TABLE 9 v

SIGNIFICANT CHANGES IN SEASONAL MEAN VALUES AT STATIONS ON THE MAIN RIVER AND ITS TRIBUTARIES.

Station	Seasons I-II	Seasons II-III	Seasons III-IV
Main River			
1	*	*	
2	*		
3	*	*	*
4		*	
5		*	
6		*	*
7		*	*
8		*	
9		*	*
10		*	*
Hammer Stream			
11	*		
Batts Brook			
12	*		
13	*		
Colhays Stream			
14			
15	*		
16	*		
Ashford Stream			
17	*		
18		*	
19		*	
Tilmore Brook			
20		*	
21	*		*
22	*		*
Stanbridge Stream			
23			
24	*		
25	*		
26		*	
Crundle Stream			
27	*		*
28			*
29			
30			

TABLE 9 v cont.

Station	Seasons I-II	Seasons II-III	Seasons III-IV
Harting Stream			
31	*		
32			
33			
34			
Dumpford Park Stream			
35	*		
Goldrings Stream			
36	*	*	*

* - not significantly different at 0.10 level.
Using paired t test

two seasons apart are significantly different and the one between is not significantly different from one or both and its value is between the first two means then there is still a significant monotonic decrease. Using this criterion then a total of twenty one sites are considered to show pattern 1. Similarly, in spite of some non-significant differences between adjacent seasonal means, a total of seven stations show pattern 2, although at stations 12, 13, 22 and 31 there may not be an increase from season I to IV.

The existence of pattern 2 at a station was interpreted as meaning that the flow at these sites was predominantly delayed flow. Each of these sites is below a basin which is dominated by permeable lithologies though there are sites with the same characteristic which show pattern 1, ie stations 18, 19, 27, and 28. These four sites are distinguished by being below basins with very high percentages of their areas in arable land use

Station	% of basin in arable
18	35.9
19	30.6
27	51.2
28	51.4

This inspection of the data shows that it is likely that the relations found at the site scale are manifest at the basin scale too. In order to examine the contention further a multiple linear regression model, expressing the relation between the four factors and NO_3-N values was assumed.

As the only factor which has a time variation is season the regression model takes the form:

$$\bar{N}_i = a + f(X_1 , X_2 , \ldots\ldots X_n) + e$$

where $\bar{N}_i$ is a seasonal mean value for particular conditions of discharge state, land-use and geology; e , the error term is assumed to be normally distributed about a mean of zero, and a is a constant.

The site data showed complex relations between the four factors and NO_3-N values, which included significant interaction effects. Two of the factors, season and discharge must be treated as dummy variables. This is equivalent to an analysis of variance. Four seasons can be represented by three dummy variables, S_1 , S_2 , S_3 . During season I, $S_1=1$ and $S_2= S_3= 0$ and so on. During season IV , $S_1=S_2=S_3=0$. Similarly discharge state was represented by D, taking the value 0 for delayed flow conditions and 1 for quickflow conditions. Geology was represented by the % area in each sub-basin underlain by each lithology (C, U, G and L). Land use was represented by the % total area in arable use, A.

However, the analysis of river data and of site data showed the presence of interactions which had to be taken account of. Seasonal changes, for instance, are different for quickflow and delayed flow conditions and the effects of land-use and geology differ according to season and discharge state. These effects can be represented by interaction terms in the regression

For example the equation ,

$$\bar{N}_1 = a + b_1S_1 + b_2S_2 + b_3S_3 + b_4D + b_5X$$

where b's are regression coefficients and X is an independant variable representing land-use(or geology) , can be made to include interaction effects, and then expands to become:

$$N_1 = a + b_1S_1 + \ldots + b_5X + b_6(S_1X) + b_7(S_2X) \ldots + b_9(DX)$$

Only interactions between the dummy variables and X are considered but other interactions are equally valid.

A model using dummy variables but no interaction terms can be represented by a set of parallel lines (Fig. 9 i) on the $\bar{N}_i$ - X plane, whereas the use of interaction terms allows for differences in the slope of the regression functions according to which category of dummy variable is employed (Fig. 9 ii). This latter regression model contains all the information needed to write a separate regression equation for each category of the dummy variable

$$\bar{N}_i = (a + b_1) + (b_5 + b_6)X$$

when $S_1=1$ and $S_2=S_3=0$, abd so on.

There are four seasons, two discharge states, four geologies and two land-use categories, and thus the total number of interactions is two hundred and ten. The model is to be calibrated and tested against mean values from the set of thirty six sub-basins. Because of the pattern of tributaries only ten independant basins can be chosen. These are the sub-basins which occupy the headwaters of the main river and tributaries.

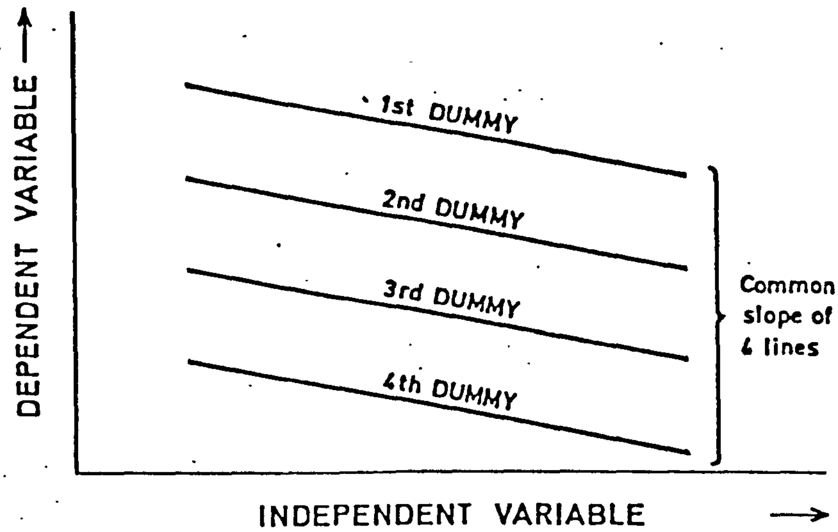


Fig. 9.i Graphical Representation of the Effect of Dummy Variables

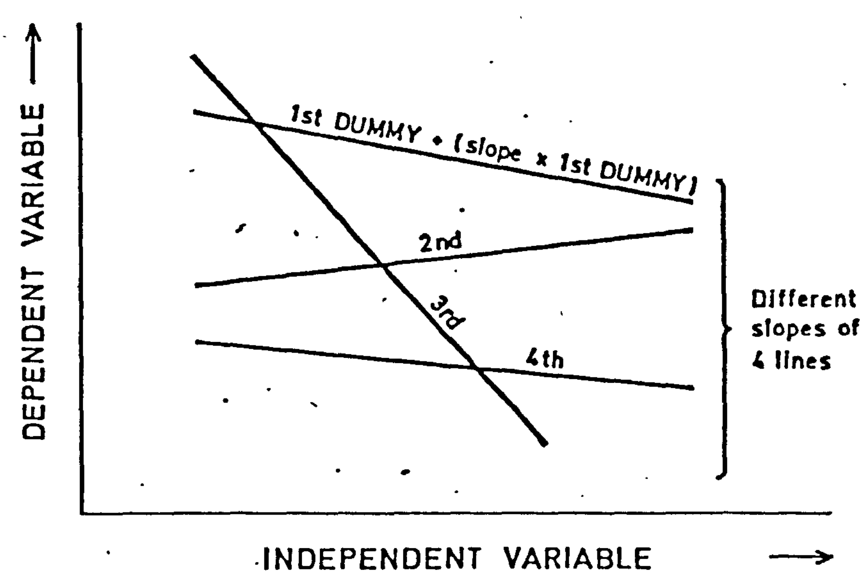


Fig 9 ii Graphical Representation of the Effect of Dummy Variables with Interaction Effects in Multiple Regression.

Thus there are only eighty seasonal mean values for calibrating the model so clearly the full interaction model cannot be employed without modification.

A smaller number of variables were chosen which it was hoped would provide a suitable set of independent variables in a regression model. The interacting effects of season and discharge were represented by a set of seven dummy variables, S_1 to S_7. These took the values 1 0 0 0 0 0 0 during delayed flow conditions of season I and so on, until 0 0 0 0 0 0 0 represented quickflow conditions in season IV.

The most significant effect of land use and geology is due to the interaction of arable land use and Gault. This was represented by a variable, GA, the % of the total basin area on Gault and in arable land-use. A second set of variables representing the changing seasonal and discharge effects were produced as interactions between GA and S_1 to S_7. GA cannot be used alone to describe the land use/geology characteristics of a basin since several basins do not contain any area on Gault but are still manifestly different. A second geology variable was used (L+C) to represent the effect of rocks very different from Gault. The sum of % areas on Chalk and Lower Greensand was used to ensure that each basin should be represented by at least one of these two variables. For no basin did L=C=GA=0. A set of interaction variables between (L+C) and S_1 to S_7 was also used.

Thus a total of twenty three variables were employed in the regression model. A stepwise proceedure was used to generate a regression equation. This is summarised in Table 9 vi. Only the first eight steps are considered. By this stage over 80% of the sum of squares in the dependent variable is accounted for. The eventual multiple R^2 value is 0.8377 after the addition of 20 variables.

The first variable to enter is GA, which alone accounts for 70.2% of the total sum of squares. The second variable is S_4, the interaction between high discharge events and season I. The coefficient +1.37 indicates that the mean values are higher by this amount over other conditions. Other variables enter with little further improvement in R^2. It is noticeable that $(L+C)S_4$ and $(L+C)$ have very small coefficients. The only negative coefficient in the first eight variables selected is -0.70 for S_7, the condition for low discharge events in season IV. The higher readings of season II low discharge events are also shown in the equation and the interaction between GA and high discharge events in seasons I and II.

Each of these characteristics is one which was shown for the data from sites and by inspection of the weekly values at the stations.

The equation after the addition of eight variables is:

$$N = 0.64 + 0.78GA + 0.01(L+C) + 1.37S_2 + 0.55S_3 - 0.70S_7 + 0.21GA.S_2 + 0.22GA.S_4 + 0.01(L+C).S_4$$

SUMMARY OF STEPWISE REGRESSION PROCEDURE.

Dependent Variable:

1	Mean NO_3-N concentration in p. p. m. for a sub-basin controlled for season and discharge state.

Independent Variable:

2	GA, % area of basin in arable land use on Gault.
3	L+C, % area of basin on Chalk and Lower Greensand.
4	S1, 1 for delayed flow in season I, 0 otherwise.
5	S 2, 1 for quickflow in season I, 0 otherwise.
6	S3, 1 for delayed flow in season II, 0 otherwise.
7	S4, 1 for quickflow in season II, 0 otherwise.
8	S5, 1 for delayed flow in season III, 0 otherwise.
9	S6, 1 for quickflow in season III, 0 otherwise.
10	S_7, 1 for delayed flow in season IV, 0 otherwise
11	$GA.S_1$, interaction of GA and S_1.
..	..
17	$GA.S_7$, interaction of GA and S_7.
18	$(L+C).S_1$, interaction of (L+C) and S_1.
..	
24	$(L+C).S_7$, interaction of (L+C) and S_7.

Step	Regression Equation	R^2	F-value
1	(1)=0.799(2)+1.611	0.702	184
2	(1)=0.799(2)+1.761(5) + 1.39	0.748	14.1
3	(1)=0.809(2)+1.959(5) +0.032(21)+1.16	0.787	14.1
4	(1)=0.836(2)+1.938(5) +0.029(21)+0.013(3) +0.554	0.801	4.9

TABLE 9 vi, cont.

Step	Regression Equation	R^2	F-value.
5	(1)=0.838(2)+1.802(5) +0.026(21)+0.013(3) -0.848(10)+0.678	0.811	4.0
6	(1)=0.814(2)+1.835(5) + 0.019(21)+0.014(3) - 0.814(10)+0.193(14) +0.669	0.817	2.5
7	(1)=0.784(2)+1.267(5) +0.018(21)+0.014(3) -0.812(10)+0.217(14) +0.215(12)+0.740	0.823	2.2
8	(1)=0.782(2)+1.372(5) +0.019(21)+0.014(3) -0.704(10)+0.226(14) +0.216(12)+0.556(6) +0.644	0.827	1.7

The residuals are presented in Table 9 vii. With over 80% explained variance the model can be regarded as successful statistically but it is important to examine the residuals for patterns. There appear to be autocorrelations in the set as they tend to be all positive or negative for some groups of eight mean values associated with particular sub-basins. However, it is necessary to define the acceptable inaccuracy in estimates. There is no entirely satisfactory method as both percentage error and absolute error need to be considered. However, the main patterns in residuals can be identified considering absolute errors and there is no need to consider the standard error of the estimates for each mean value. The margin of error used is 1.0 units.

Considering the individual sub-basins there are only large and consistent errors in the case of sub-basin 1, where the computed values are higher than the observed by at least 1.5. Similarly within sub-basin 2 the computed values are all higher but four of them by less than 1.0. There is no discernable reason why these two basins should show such large anomalies.

There is some tendancy for high anomalies to be shown for quickflow conditions in season 1 where the estimates are less than the observed values. This can be interpreted as a flushing effect. However, it does not apply to all basins and those to which it does apply have no marked similarities in land use or geology.

Basin 27 shows an interesting pattern of alternating positive and negative residual values but most are less than 1.0. Only for quickflow conditions in seasons 1and 11 are the residuals large.

TABLE 9 vii

TABLE OF ACTUAL, PREDICTED AND RESIDUAL VALUES FROM THE STEPWISE REGRESSION MODEL OF MEAN NITRATE NITROGEN CONCENTRATIONS FOR HEADWATER SUB-BASINS.

		Seasons							
Basin		I		II		III		IV	
		D	Q	D	Q	D	Q	D	Q
1	O	2.0	2.5	1.8	2.4	1.3	2.0	0.9	1.6
	C	3.5	5.4	4.0	5.1	3.2	3.8	2.8	3.4
	R	-1.5	-2.9	-2.2	-2.7	-1.9	-1.8	-1.9	-1.8
2	O	3.9	4.8	3.1	3.9	3.4	3.5	3.2	3.5
	C	4.1	6.7	4.8	5.6	4.0	4.4	3.7	4.6
	R	-0.2	-1.9	-1.7	-1.8	-0.7	-0.9	-0.5	-1.1
12	O	2.3	4.1	3.3	3.7	2.4	3.1	1.9	2.6
	C	2.1	4.0	2.9	3.5	2.1	2.8	1.6	2.4
	R	0.2	0.1	0.4	0.2	0.3	0.3	0.3	0.2
14	O	2.3	4.3	4.5	4.8	3.6	3.9	3.0	3.4
	C	3.4	6.2	4.4	4.9	3.7	3.9	3.2	4.2
	R	-1.1	-1.9	0.1	-0.1	-0.1	0.0	0.0	-0.8
17	O	2.1	2.9	2.4	2.6	1.9	2.3	1.6	2.0
	C	1.7	3.0	2.3	3.1	1.4	2.4	0.9	1.4
	R	0.4	-0.1	0.1	-0.5	0.5	-0.1	0.7	0.6
23	O	1.4	2.81	2.9	2.9	1.8	2.2	1.1	2.4
	C	0.1	2.4	1.5	1.3	0.8	1.3	0.2	1.3
	R	1.3	0.4	1.4	1.6	1.0	0.9	0.9	1.1

/ cont.

TABLE 9 vii, cont.

Basin		Seasons. I D	I Q	II D	II Q	III D	III Q	IV D	IV Q
27	O	0.8	4.0	2.0	4.1	0.7	2.9	0.2	1.0
	C	1.5	2.9	2.2	3.0	1.4	2.3	0.8	1.4
	R	-0.7	1.0	-0.2	1.1	-0.7	0.6	-0.6	-0.4
31	O	1.9	4.0	2.8	3.1	1.9	2.3	1.2	1.7
	C	1.6	2.9	2.2	3.0	1.4	2.3	0.8	1.4
	R	0.3	1.1	0.6	0.1	0.5	0.0	0.4	0.3
35	O	5.3	11.4	6.1	7.1	5.0	5.2	4.7	6.5
	C	4.8	7.6	5.5	6.3	4.8	4.9	4.4	5.4
	R	0.5	3.8	0.6	0.8	0.2	0.3	0.3	1.1
36	O	10.4	12.0	10.0	13.1	8.9	9.2	8.5	8.8
	C	9.7	11.7	9.0	11.9	8.1	8.5	7.9	8.2
	R	0.7	0.3	1.0	1.2	0.8	0.7	0.6	0.6

D= delayed flow conditions

Q= quickflow conditions.

O= observed value

C= computed value in NO_3-N ppm.

R residual value

This sub-basin is mostly in lower Chalk and this sort of land can be expected as a heavy type which would account for these anomalies. For the conditions of season and discharge there are no discernible patterns of positive or negative anomalies.

The equation shows the dominant effect of arable land use on Gault and the distinct characteristic of quickflow events in season I (S_2) . The effect of Chalk and Lower Greensand is small but significant. The other interacting dummy variables show the importance of both quickflow and delayed flow in season II, woth higher concentrations and the lower concentrations in delayed flow events in season IV.

These coefficients are in some sense an artifact as there is no special reason for including only seven variables other than that with addition of new variables changes in R^2 are negligible. With different steps in the stepwise process the coefficients change and one variable, S_3, is removed.

PART 10

SEASONAL PREDICTION OF MEAN VALUES OF NITRATE CONCENTRATION

The regression model applies to sub-basins which occupy the heads of the tributary streams. It is unlikely to apply to different kinds of basins without alteration of the coefficients or even reselection of independent variables depending on the characteristics of other basins. However, a test of the relations expressed in the model can be made in two ways:

i by estimating NO3-N concentrations in the remaining sub-basins, which are downstream of those used to calibrate the model, and assuming that the effects of adjacent basins are additive when computing estimates at successive downstream stations.

ii by estimating NO3-N concentrations for a year with different conditions of land use and discharge and comparing with actual observations.

These lead on to and involve a second set of problems:

a. the prediction of NO3-N concentrations in large basins.

b. predicting time changes of NO3-N concentrations.

c. predicting weekly, or other short time period variations.

Each of these second set of problems requires an extension of the use of the four parameters and the addition of new information. The fundamental problem of this thesis is to what extent can NO3-N values be predicted on the basis of simple, easily measured information. Thus the crucial question which arises is what new information needs to be added to predict successfully under the new conditions.

The model deals with mean NO_3-N values for either of the two discharge states in a season. At this degree of resolution in time it is assumed that discharges from different sub-basins are proportional only to their area. Therefore assuming that a unit area yields a unit volume of water, these volumes can be routed through a network model in order to calculate concentrations at stations on tributaries and the main stream.

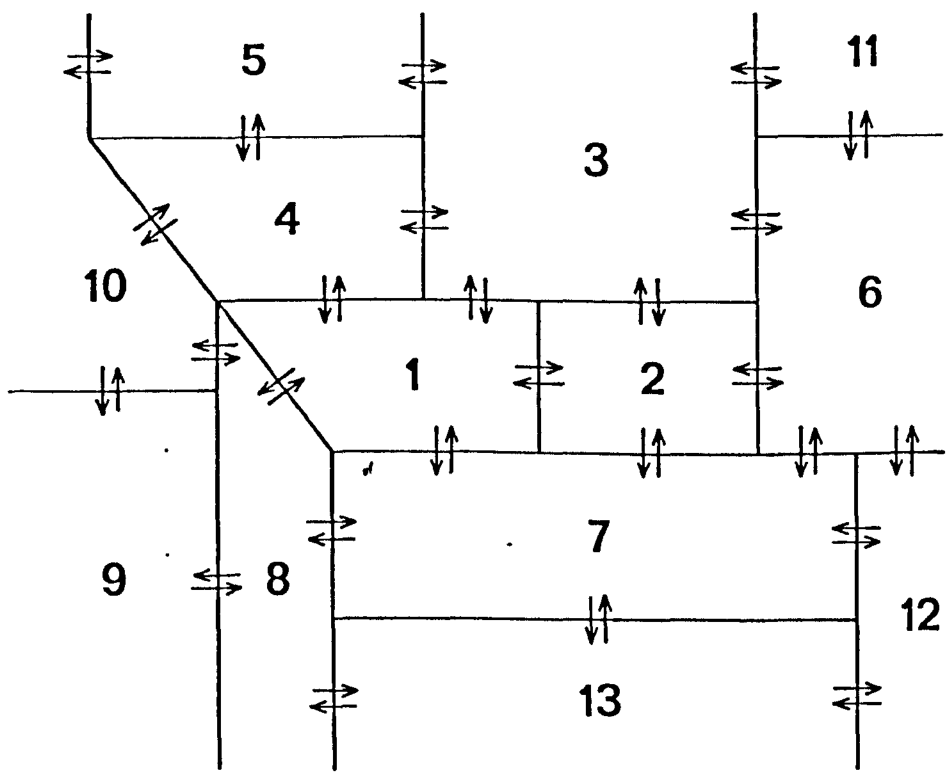
Rich (1973) presents a general model for the transport of solutes in river systems. He represents the transport system as a two-dimensional lattice (Fig. 10 i) defining a set of discrete fluid volumes. Transport between adjacent volumes is indicated by arrows. Each volume is considered homogeneous along the third dimension. A river system can be regarded as a variety of such a lattice with many non-transmitting boundaries.

The finite model takes the form:

$$V_i \frac{dc}{dt}_1 = \sum_j (G_{ji} + D_{ji}) - S_i \qquad \text{III}$$

where $\frac{dc}{dt}_1$ is the time rate of change of concentrations of material in volume i ; V_i is the volume of fluid in volume i ; G_{ij} is the transport of material from j to i by advection; D_{ij} is the transport of material from j to i by dispersion; and S_i are sources and sinks of material in volume i.

The advection term may be expressed as:



NOTE: For river systems most of the exchanges are redundant.

Fig. 10.i Environmental Medium Segmented in a Two-Dimensional Lattice (Rich, 1973).

$$G_{ji} = Q_{ji} \left[d_{ji}\, c_j + (1-d_{ji})\, c_i \right]$$

where Q_{ji} is the volume of transport fluid from j to i; d_{ji} is a net advection factor.

The dispersion term can take the form:

$$D_{ji} = E_{ji}(c_j - c_i)$$

where E_{ji} is a mixing coefficient.

For non-tidal streams the quantity of material transported downstream at a boundary is related only to the material upstream and the downstream concentration has no effect, thus $d_{ji} = 1.0$.

Therefore,

$$G_{ji} = Q_{ji} \cdot c_j$$

If steady state conditions are assumed for weekly periods then:

$$\frac{dc}{dt} = 0$$

and equation III can be rearranged and expanded to give:

$$(\sum E_{ji})c_i - \sum(Q_{ji} + E_{ji}) + S_i = 0$$

Rich (1973) reports one method for predicting the value of E_{ji} from stream tracer experiments based upon work by Fisher (1968):

$$E_{ij} = \frac{u^2}{2} \cdot \frac{\sigma_{t_1}^2 - \sigma_{t_2}^2}{t_2 - t_1}$$

where $\sigma_{t_1}^2$ and $\sigma_{t_2}^2$ are the variances of concentration time curves at upstream and downstream stations respectively; t_1 and t_2 are the mean times of passage of the tracer cloud past the stations; and

$\bar{u}$ is the mean velocity of flow between stations.

No experiment has been conducted on the Rother but suitable information can be taken from measurements of NO_3-N concentration at stations downstream of a sewage works which experiences a marked peak loading. Data for Durford and Habin stations below Petersfield sewage works are presented in Fig. 10 ii.

They are 4 km apart and the peak takes eight hours to pass. Estimates of $\sigma^2_{t_1}$ and $\sigma^2_{t_2}$ are 7.78 and 6.45. Using the metric values (m. s)

$$E = \frac{0.25}{2} \cdot \frac{(7.78 - 6.45)}{28.80}$$

$$= 5 \times 10^{-6} \quad (\text{approx})$$

The value of E will differ for different reaches and flow conditions but is likely to remain very small relative to Q_{ji} and therefore can be ignored.

These assumptions allow equation III to reduce to

$$-\sum_j (Q_{ji}) c_i + S = 0$$

which can be operated using simple addition and subtraction of volumes from various sub-basins.

Thus, if the mean concentration of NO_3-N from two adjacent sub-basins (c_1 and c_2) is calculated from the regression model then the mean concentration in the stream below both, ie. c_3 is adequately given by:

$$c_3 = \frac{A_1 c_1 + A_2 c_2}{A_1 + A_2}$$

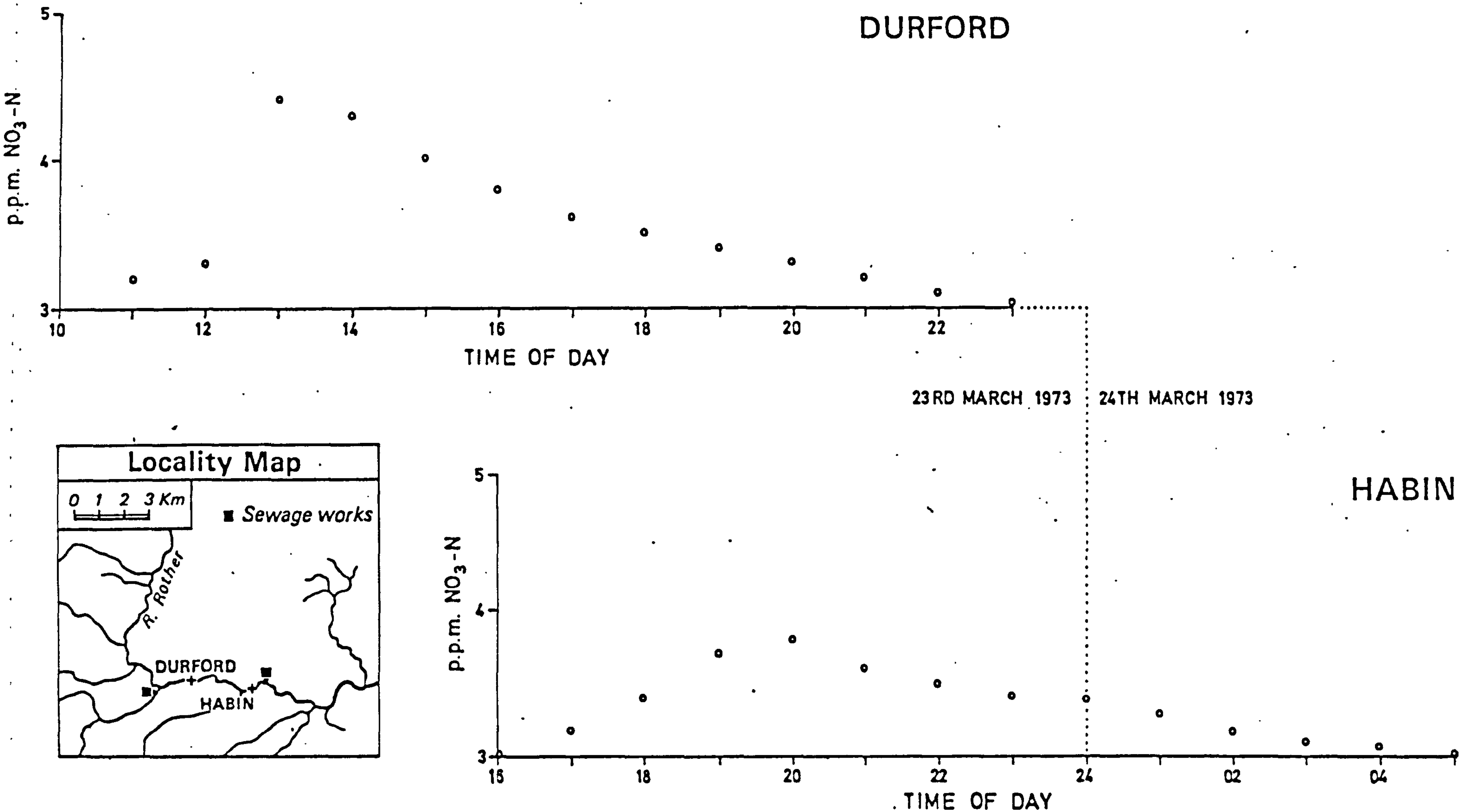


Fig. 10 ii Nitrate Nitrogen Concentrations at Durford and Habin - 23rd March 1973.

where A_n is the area of a sub-basin, n , and equal areas are assumed to produce equal yields.

However, there are two problems which need to be considered before the regression model can be applied to the Rother basin:

i. the changing behaviour of the river as it changes size.

ii. the effects of sewage works.

Many of the sub-basins are larger than those upon which the regression is based. It was noted above that the importance of the four factors in explaining the relative proportions of the variance in NO_3-N values was different at the site scale from the sub-basin scale. In particular differences of discharge state were more important at the sub-basin scale. The regression model for mean NO_3-N values takes no account of sub-basin scale but no systematic anomalies in residual values (Table 9 vii) were noted.

In order to test whether the importance of the discharge state changed in relation to the sub-basin size a series of analyses of variance procedures were carried out on mean NO_3-N values, grouped according to size. These are summarised in Table 10 i. It must be noted that each cell of all of the analyses contained only two values because of the small number of basins and therefore the results may not be very reliable. The highest % variance explained relates to the largest set of sub-basins but high explained variances are also found in smaller groups of basins. Two groups of basins have no significant discharge effects. From this it is concluded that there is no clear evidence that the importance of

TABLE 10 i

SUMMARY OF ANALYSIS OF VARIANCE ON NO_3-N VALUES FROM DRAINAGE BASINS OF VARIOUS SIZES.

1. 0-100 hectares:

Effect	SS	Df	Ms	F	
Discharge	115.0	1	115.0	2.36	n. s.
Season	75.0	3	25.0		n. s.
Interaction	52.7	3	17.5		n. s.
Residual	389.6	8	48.7		
Total		15	206.2		

2. 100-200 hectares:

Effect	SS	Df	Ms	F	
Discharge	14.6	1	14.6	6.3	% exp. -63%
Season	12.5	3	4.17	1.8	n. s
Interaction	6.4	3	2.1		n. s
Residual	19.1	8	2.3		
Total		15	23.1		

3. 200-300 hectares:

Effect	SS	Df	Ms	F	
Discharge	3.1	1	3.1	7.2	% exp. -55%
Season	5.1	3	1.7	3.9	n. s.
Interaction	1.6	3	0.5		n. s.
Residual	3.5	8	0.43		
Total		15	5.6		

4. 300-400 hectares:

Effect	SS	Df	Ms	F	
Discharge	14.2	1	14.2	1.4	n. s.
Season	6.8	3	2.2		n. s.
Interaction	6.5	3	2.1		n. s.
Residual	76.9	8	9.6		
Total		15	28.1		

TABLE 10 i, cont.

5. 400-600 hectares:

Effect	SS	Df	Ms	F	
Discharge	14.3	1	14.3	3.5	% exp. 64%
Season	5.2	3	1.7		n.s.
Interaction	1.9	3	0.6		n.s.
Residual	33.1	8	4.1		
Total		15	20.7		

6. 600 + hectares:

Effect	SS	Df	Ms	F	
Discharge	11.7	1	11.7	5.6	% exp. -75%
Season	4.7	3	1.5		n.s.
Interaction	1.0	3	0.3		n.s.
Residual	17.5	8	2.1		n.s.
Total		15	15.6		

n.s. = not significant.
significance level used 10%
($F_{1,8}$ = 3.46)

discharge state is related to sub-basin size and that any relation with scale relates to differences between individual sites and sub-basins. More extensive data may demonstrate otherwise.

The discharges from each sub-basin were assumed to be proportional to the area irrespective of season or discharge state and therefore the simple ratio of sub-basin area to the total area of the basin could be used to calculate concentrations in the main river and its tributaries . Sewage effluents were included in the concentrations by assuming the area of the works to be equal to the ratio of the mean effluent discharge to the mean discharge at Iping. Seasonal differences in flow were incorporated into the model using data from the Petersfield works. The 'areas' of the other works were in constant ratio to that at Petersfield.

The mean values estimated for all the sub-basins are presented in Tables 9 vii and 10ii. Mean values estimated for each station using the sub-basin values in the mixing model are also presented against the mean ones.

The residuals for the sub-basins used in the regression model are in Table 9 vii and will not be discussed further. Residuals (Table 10 ii) for the stations below the tributary heads and not affected by sewage works are not as satisfactory as the former set. Very large and consistent anomalies are shown. There appears to be no consistent anomalies when considering seasons or discharge states, but for individual basins they are uniformly high or low. There

TABLE 10 ii A.

OBSERVED AND PREDICTED VALUES - TRIBUTARIES NOT BELOW SEWAGE WORKS.

Station	Measured								Predicted						
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7
13	2.0	4.1	2.9	5.5	2.0	3.9	1.1	2.0	4.8	9.4	5.5	8.4	4.7	6.1	4.1
15	3.7	15.5	6.3	11.6	4.5	7.8	3.5	5.3	14.1	20.3	13.5	19.0	12.8	13.4	12.4
16	3.2	12.3	5.0	10.3	3.1	6.5	1.8	3.0	12.9	18.0	12.3	17.0	11.7	12.1	11.2
18	2.7	4.4	2.5	3.3	2.2	3.2	2.0	2.3	3.2	5.7	3.9	5.1	3.1	3.9	2.5
19	2.6	4.5	2.5	3.5	2.2	3.1	2.0	2.3	3.0	5.2	3.5	4.9	2.7	3.7	2.2
24	2.0	7.3	3.7	5.8	2.0	5.3	1.4	3.4	8.6	11.5	8.4	10.8	7.7	7.8	7.4
25	1.5	6.9	3.4	5.4	2.0	3.9	1.4	3.6	7.5	10.1	7.4	9.6	6.7	7.0	6.3
28	2.3	4.1	2.6	3.3	2.0	3.1	1.7	2.8	0.5	2.5	1.7	1.7	0.9	1.6	0.4
29	1.9	5.1	2.4	3.6	1.2	2.2	0.5	1.0	0.4	2.5	1.7	1.6	0.9	1.5	0.4
30	3.0	6.0	2.4	3.8	1.3	2.2	1.0	1.3	3.0	5.6	3.8	4.7	3.0	3.7	2.5
3	2.8	3.3	2.6	3.2	2.3	3.7	2.3	2.4	3.6	5.5	4.0	5.3	3.2	3.9	2.7

Residuals

8	1	2	3	4	5	6	7	8
6.3	-2.8	-5.3	-2.6	-2.8	2.7	-2.2	-3.0	-4.3
15.0	-10.4	-4.8	-7.2	-7.4	-8.3	-5.6	-8.9	-9.7
13.2	-9.7	-5.7	-7.3	-6.3	-8.6	-5.6	-9.4	-10.2
3.6	-0.5	-1.3	-1.4	-1.8	-0.9	-0.7	-0.5	-1.3
3.2	-0.4	-0.7	-1.0	-1.4	-0.5	-0.6	-0.2	-0.9
8.2	-6.6	-4.1	-4.7	-5.0	-5.7	-1.5	-6.0	-4.8
7.1	-6.0	-3.2	-4.0	-4.2	-4.7	-3.1	-3.9	-3.5
1.3	1.8	1.6	0.9	1.6	1.1	1.5	1.3	1.5
1.3	1.5	2.6	0.7	2.0	0.3	0.7	0.1	-0.3
3.6	0.0	0.4	-1.4	-0.9	-1.7	-1.5	-1.5	-2.3
3.5	-0.8	-2.2	-1.4	-2.1	-0.9	-0.2	-0.4	-1.1

TABLE 10 ii B

OBSERVED AND PREDICTED VALUES AT STATIONS BELOW SEWAGE WORKS.

Station	Measured								Predicted						
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7
4	4.4	4.1	3.4	3.6	3.5	4.1	3.4	3.3	4.7	6.3	4.7	5.9	4.3	4.8	4.3
5	3.7	4.2	3.0	3.9	2.9	4.0	2.7	2.9	4.5	6.4	4.5	6.1	4.0	4.8	3.9
6	5.1	4.9	3.8	4.2	4.1	4.6	4.7	3.4	5.0	6.4	4.8	6.2	4.4	4.9	4.4
7	4.1	4.8	3.6	4.3	3.1	4.3	3.1	3.6	4.6	6.1	4.5	5.8	4.0	4.6	3.9
8	4.5	5.2	3.7	4.4	3.4	4.2	3.1	3.5	4.1	5.4	4.1	5.2	3.6	4.1	3.5
9	5.0	5.4	3.7	4.3	3.6	4.4	3.7	3.9	4.1	5.4	4.1	5.3	3.6	4.1	3.5
10	4.7	5.4	3.8	4.4	3.4	4.4	3.3	3.7	3.6	4.9	3.7	4.7	3.2	3.7	3.0
26	6.3	6.8	3.9	5.2	3.7	4.3	5.6	3.5	5.7	8.2	6.0	7.5	5.3	5.6	4.9
32	8.7	5.2	4.9	4.5	7.0	5.8	8.9	5.3	2.2	3.0	2.4	2.6	2.0	2.5	2.0
33	7.1	5.6	4.3	3.8	5.6	4.0	8.0	4.5	2.3	4.1	2.9	3.3	2.4	2.9	2.2
34	7.9	5.3	4.4	3.9	6.0	4.4	6.8	4.9	2.3	4.1	2.9	3.3	2.3	2.9	2.1

Residuals

8	1	2	3	4	5	6	7	8
4.7	-0.3	-2.1	-1.3	-2.3	-0.8	-0.7	-0.9	-1.4
4.6	-0.8	-2.2	-1.5	-2.2	-1.1	-0.8	-1.2	-1.7
4.7	0.1	-1.5	-1.0	-2.0	-0.3	-0.3	-0.3	-1.3
4.4	-0.5	-1.3	-0.9	-1.5	-0.9	-0.3	-0.8	-0.8
3.8	0.4	-0.2	-0.4	-0.8	-0.2	0.1	-0.4	-0.3
3.9	0.9	0.0	-0.4	-1.0	0.0	0.3	0.2	0.0
3.4	1.1	0.5	0.1	-0.3	0.2	0.7	0.3	0.3
5.7	0.6	-1.4	-2.1	-2.3	-1.6	-1.3	0.7	-2.2
2.4	6.5	2.2	2.5	1.	5.0	2.3	6.9	1.9
2.9	4.8	1.5	1.4	0.5	2.2	1.1	5.8	1.6
2.8	5.6	1.2	1.5	0.6	3.7	1.5	4.7	1.9

could be several reasons for this pattern. The mixing model could be inaccurate, though the reason for such patterns of large residuals is not apparent. The regression model is likely to provide the main source of error. It is important to note that the failure of the model could relate to the distribution of geological types within the whole basin. Those sub-basins which occupy tributary heads are underrepresented in terms of % area on Gault - the most significant characteristic in terms of NO_3- N concentrations. Sub-basins below these have higher % area on Gault but the high coefficients relating to GA and its interactions based only on a few basins with low %GA may cause the very large, generally negative residuals.

This pattern is transmitted to some of the stations below sewage works, although the effect of inaccuracies in estimating sewage inputs cannot be gauged. It is apparent however, that at stations 32 to 34 the effect of sewage inputs seems to have been grossly underestimated and if correct values had been estimated for the main river it would have been expected that large negative residuals would have been preserved. However, the estimates for the lower stations 7, 8, 9, and 10 are remarkably good. It must be considered however, that this statistical sussess is not a valid criterion for judging the combined regression, mixing and sewage input models, as the individual parts, except the first, cannot be tested independently.

There is little basis for establishing the wider generality of the relations expressed in the regression and mixing model. Data is available for the Rother basin for the year 1967-8. NO_3-N concentrations have been measured at Iping Mill for several years, though not always on a weekly basis, and for this year land-use data is available from the Second Land Utilisation Survey. From 1:10,560 maps supplied by Miss A. Coleman the % area of arable on Gault was measured and incorporated into the regression model.

The gauging station at Iping Mill was constructed during 1968 but daily flows, computed from stage readings over a measured reach are available (fig 10 iii). Thus discharge state at a particular time could be determined.

These two variables for 1967-8 were incorporated into a revised model. The mixing model was adjusted for sewage works inputs to take account of the lower total flows during that year. The predicted mean values for Iping are presented in Table 10 iii against the measured values.

It must be noted that NO_3-N analyses for 1967-8 were made by the North West Sussex Water Board and samples were taken at irregular intervals. However, the predicted mean values show clearly that the land-use differnces are reflected in the different NO_3-N values (Table 10 iii). These differences could be due to other effects and the results do not refute any alternative hypothesis of change.

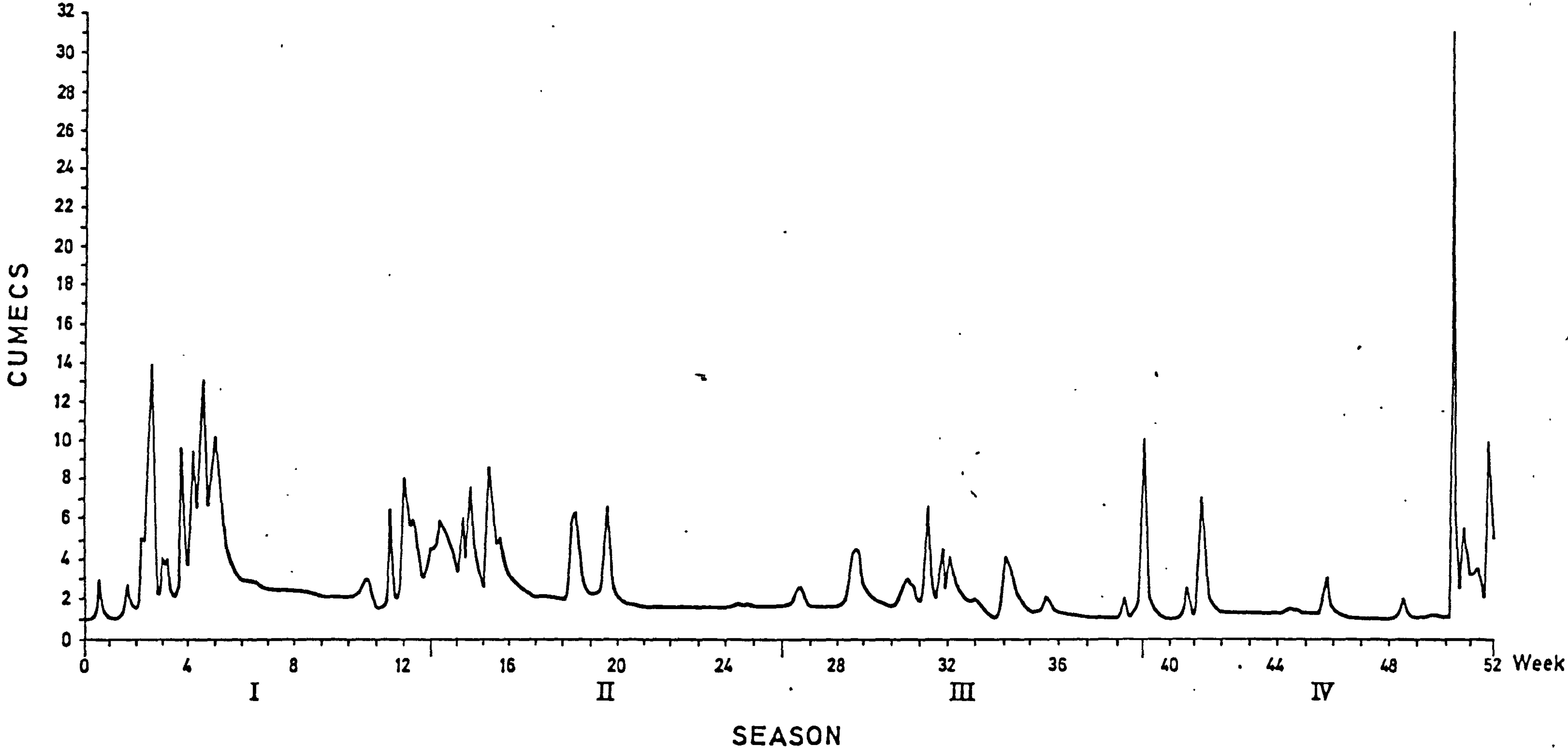


Fig. 10.iii Mean Daily Flows at Iping Mill, October 1967 to October 1968.

TABLE 10 iii

PREDICTED AND ACTUAL MEAN VALUES OF NITRATE NITROGEN AT IPING MILL 1967/8.

Mean NO_3-N concentrations:

	Season I		Season II		Season III		Season IV	
	B	Q	B	Q	B	Q	B	Q
actual	3.2	3.3	3.4	3.8	2.8	3.3	2.7	2.6
predicted	2.7	3.9	3.1	3.7	2.5	3.0	2.2	2.4

PART 11

PREDICTION OF WEEKLY VALUES

A further problem to which this thesis is directed is the prediction of NO_3-N concentrations at regular short intervals. As the only time parameter employed in the regression is season this necessitates introducing new information into the model. Two courses are open:

i. to assume that the weekly variations are stochastic variations about a seasonal mean and in the long run follow a known probability distribution.

ii. to assume that discharge variations control the variations about the seasonal mean and that other variations in NO_3-N values follow an assumed distribution.

With

1) the problem was to specify the probability distribution. It would be naive to suppose that NO_3-N values follow the same probability distribution as discharge values. There have been clear demonstrations of the close relations between the two variables (Edwards, 1974) but there are no relationships which are valid generally (Feth, 1970). Within the Rother basin most rainfall is of the frontal type. Therefore, differences in the frequency distribution of runoff between sub-basins are unlikely to be due to differences in rainfall frequency distribution. There is very little data on discharge in relation to the number of sampling stations but there are two continuous gauging stations, one on the main river at Iping Mill and one on a large Chalk spring at South Harting. However, the latter operates only sporadically and cannot be used in this analysis.

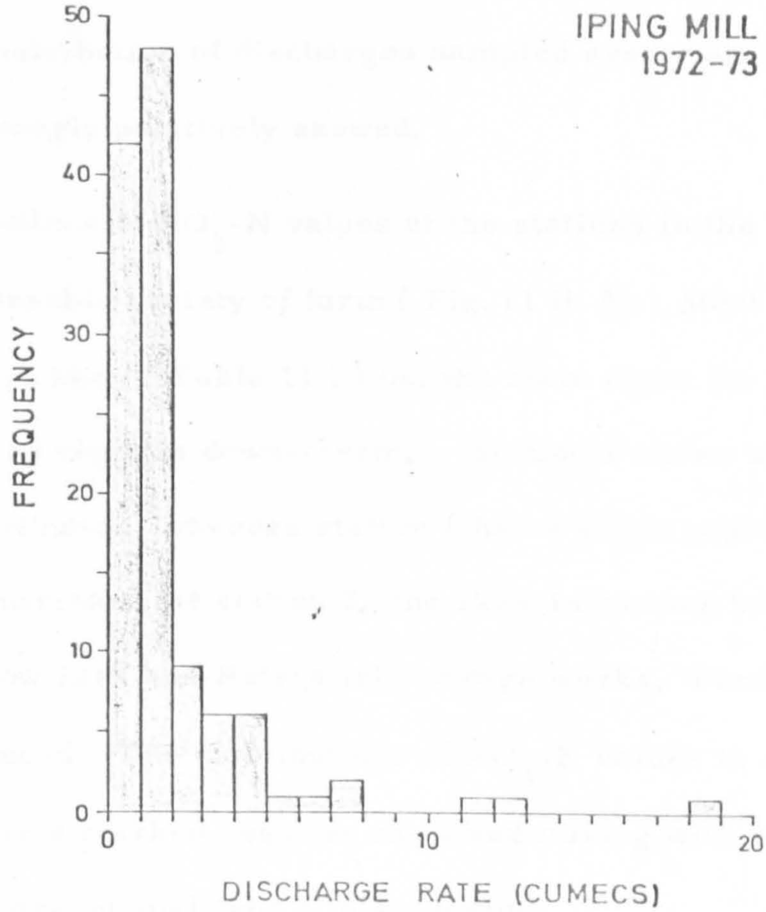


Fig. 11.i Frequency Distribution of Systematic Discharge Measurements at Iping Mill 1972 - 3.

The distribution of systematically sampled discharge rates, over time, from the continuous record at Iping Mill during 1972-3 is shown in Fig. 11 i. It shows a strong positive skew. In the absence of further information it is assumed that throughout the basin the frequency distribution of discharges sampled systematically would be strongly positively skewed.

Distributions of NO_3-N values at the stations in the basin show considerable variety of form (Fig. 11 ii A). Most have some positive skew (Table 11 i) but the main river for instance shows marked changes downstream. Station 2 shows a nearly normal distribution, whereas station 1 has a slight positive skew. Downstream, at station 3, the skew increases but at the stations below Liss and Petersfield sewage works, 4 and 6, the skew is reduced. The distributions of NO_3-N values in sewage effluents have a marked negative skew and mixing with river water leads to a more normal type of distribution.

The general pattern of distribution may be said to be log-normal and infact many workers assume this to be the case (Edwards 1974, Ledbetter and Gloyna 1969). A log-transformation however, produces distributions which still possess strong positive or negative skews (Table 11 ii), though generally the skew is reduced. For most stations the 90% confidence limit of skew values of the log-transformed data do not include the value of zero (for a normal distribution, skewness is zero).

The fact that most stations possess NO_3-N values with a

Fig.11.11 (A) Frequency Distributions of Nitrate Nitrogen Concentrations Observed at Stations on the Main River and its Tributaries.

Fig.11.11 (A) Frequency Distributions of Nitrate Nitrogen Concentrations Observed at Stations on the Main River and its Tributaries.

TABLE 11 i

SKEWNESS AND KURTOSIS FOR DISTRIBUTION OF OBSERVED NITRATE NITROGEN CONCENTRATIONS AT STATIONS ON THE MAIN RIVER AND ITS TRIBUTARIES.

Station	Skewness	Kurtosis
1	1.17	2.17
2	1.77	7.25
3	1.96	5.64
4	1.96	3.75
5	1.51	1.53
6	1.57	2.97
7	1.58	2.52
8	1.59	2.25
9	1.97	3.44
10	1.82	3.21
11	0.68	0.37
12	0.47	0.31
13	1.06	0.60
14	-0.67	0.68
15	2.50	8.30
16	2.22	6.60
17	1.01	0.92
18	2.37	6.92
19	2.65	8.71
20	-0.49	-0.27
21	0.74	0.56
22	0.91	0.63
23	0.19	-0.92
24	1.88	4.50
25	2.00	5.50
26	2.04	4.98
27	2.39	6.19
28	2.25	7.60
29	1.52	2.89
30	2.38	8.08

cont/.....

TABLE 11 i, cont.

Station	Skewness	Kurtosis
31	0.84	0.47
32	0.42	2.38
33	0.85	0.14
34	1.66	4.68
35	3.39	14.13
36	1.02	0.88

TABLE 11 ii

SKEWNESS OF DISTRIBUTION OF LOGRITHMIC VALUES OF OBSERVED NITRATE NITROGEN CONCENTRATIONS AT STATIONS ON THE MAIN RIVER AND ITS TRIBUTARIES.

Station	Skewness
1	0.037
2	0.415
3	1.098
4	1.513
5	1.139
6	0.776
7	1.067
8	1.116
9	1.510
10	1.230
11	7.210
12	-0.543
13	0.153
14	-2.238
15	-0.415
16	0.118
17	0.386
18	1.450
19	1.650
20	-1.885
21	-0.279
22	0.135
23	0.530
24	0.210
25	0.219
26	0.893
27	0.316
28	0.968
29	-0.152
30	-7.210

cont/.....

TABLE 11 ii cont.

Station	Skewness
31	0.049
32	-7.210
33	0.391
34	0.483
35	-1.000
36	0.466

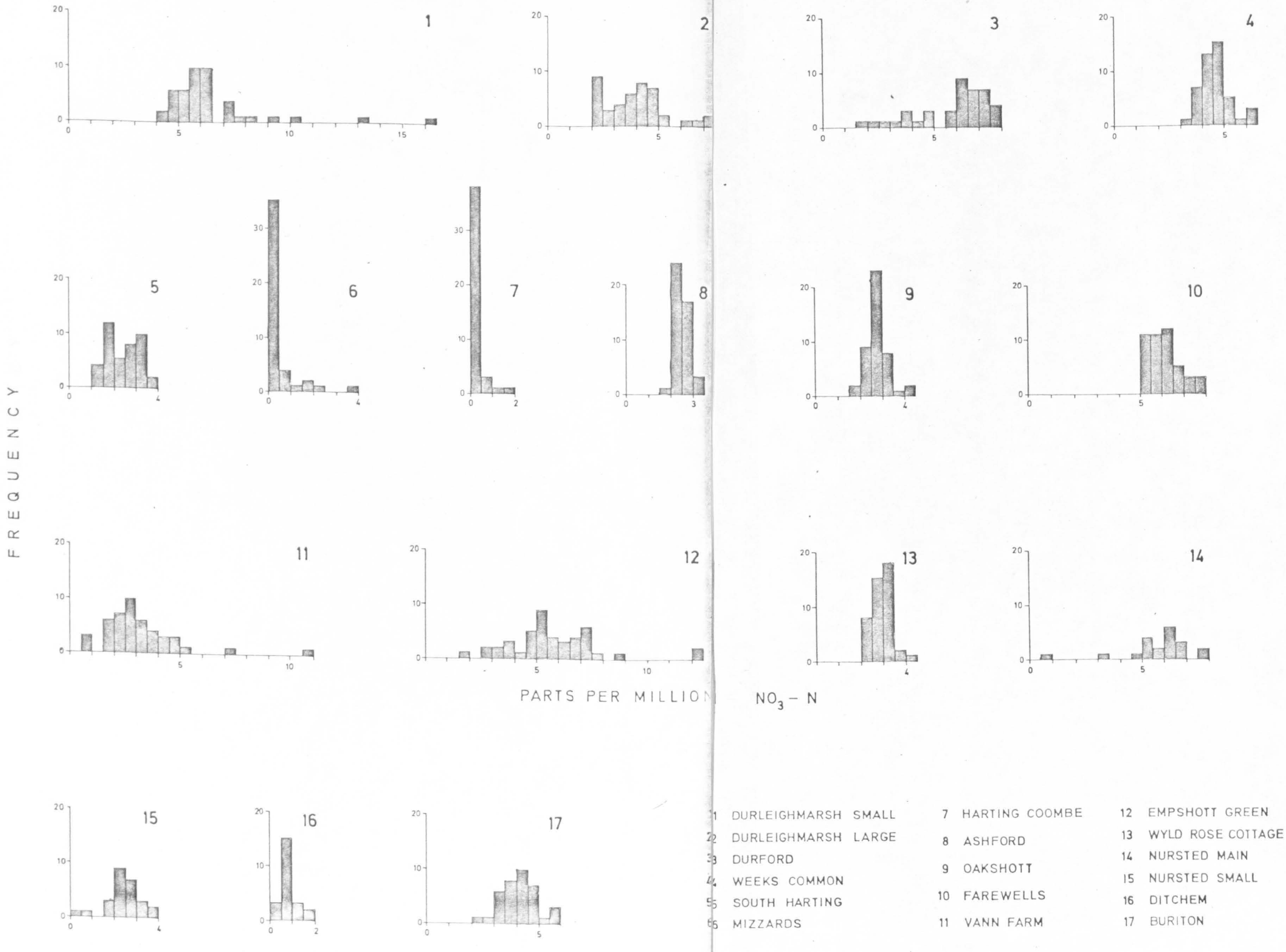


Fig.11.ii (B) Frequency Distribution of Nitrate Nitrogen Concentrations Observed at Springs.

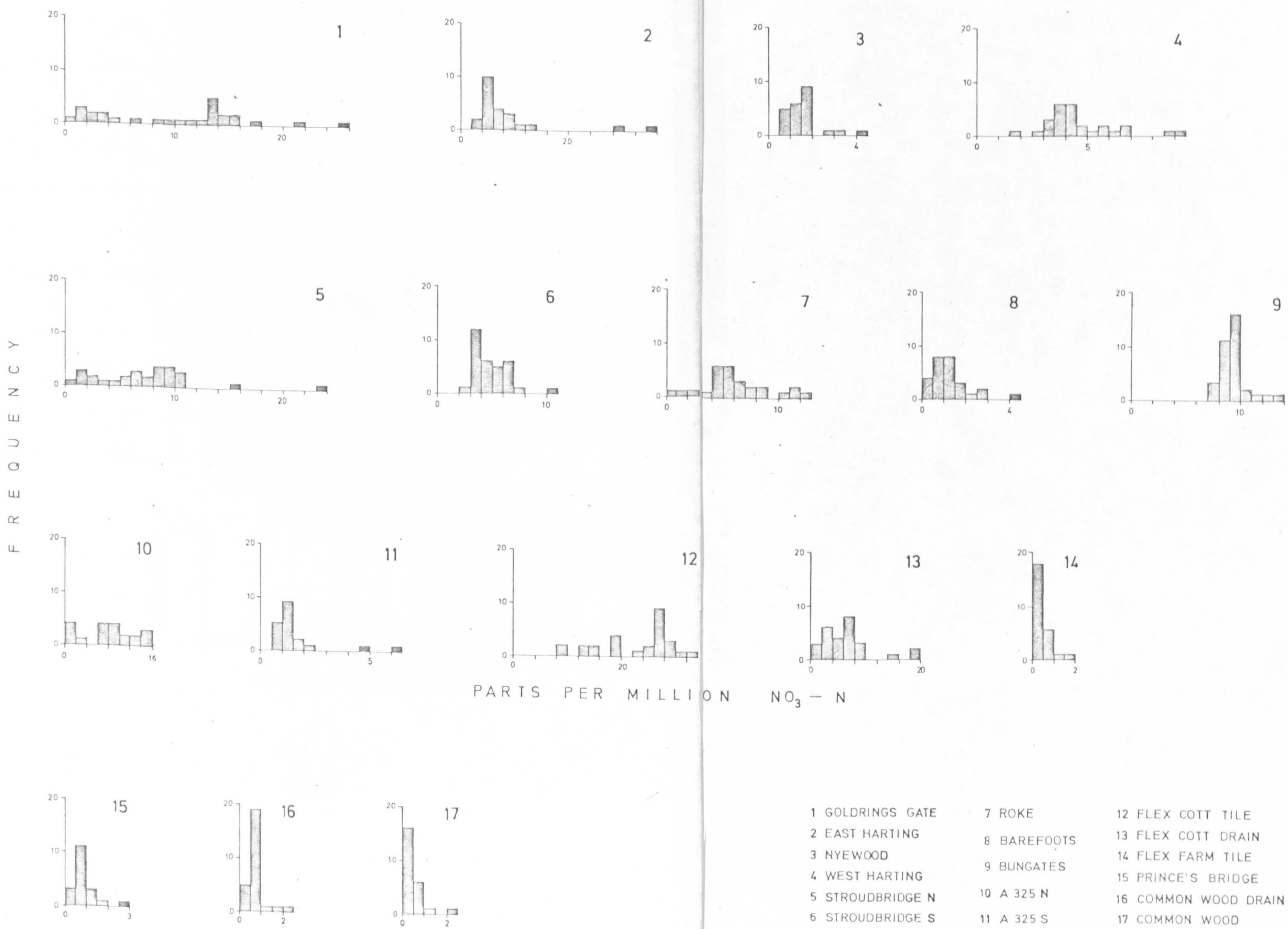


Fig.11. ii (B) Frequency Distribution of Nitrate Nitrogen Concentrations Observed at Field Drains.

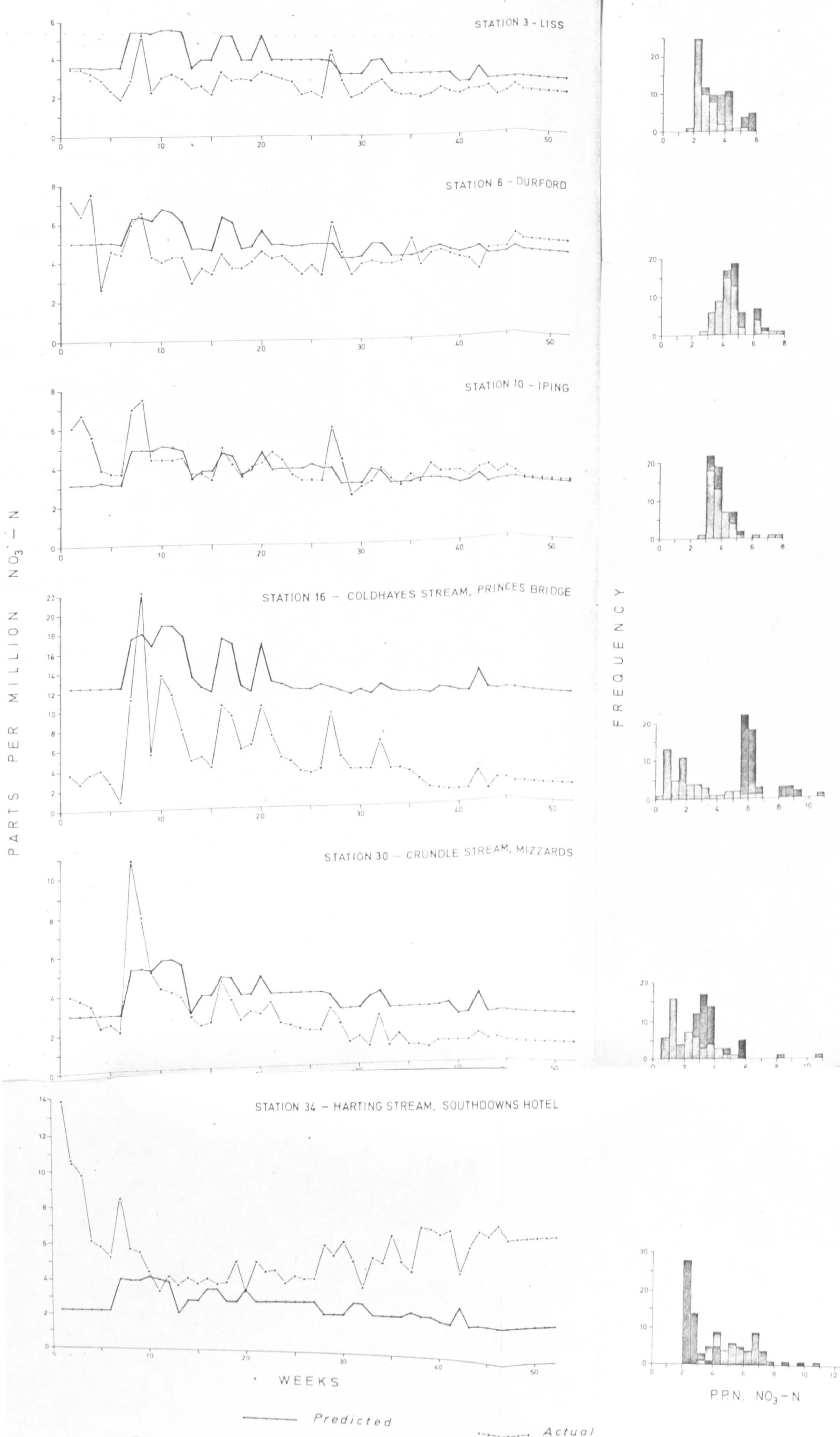
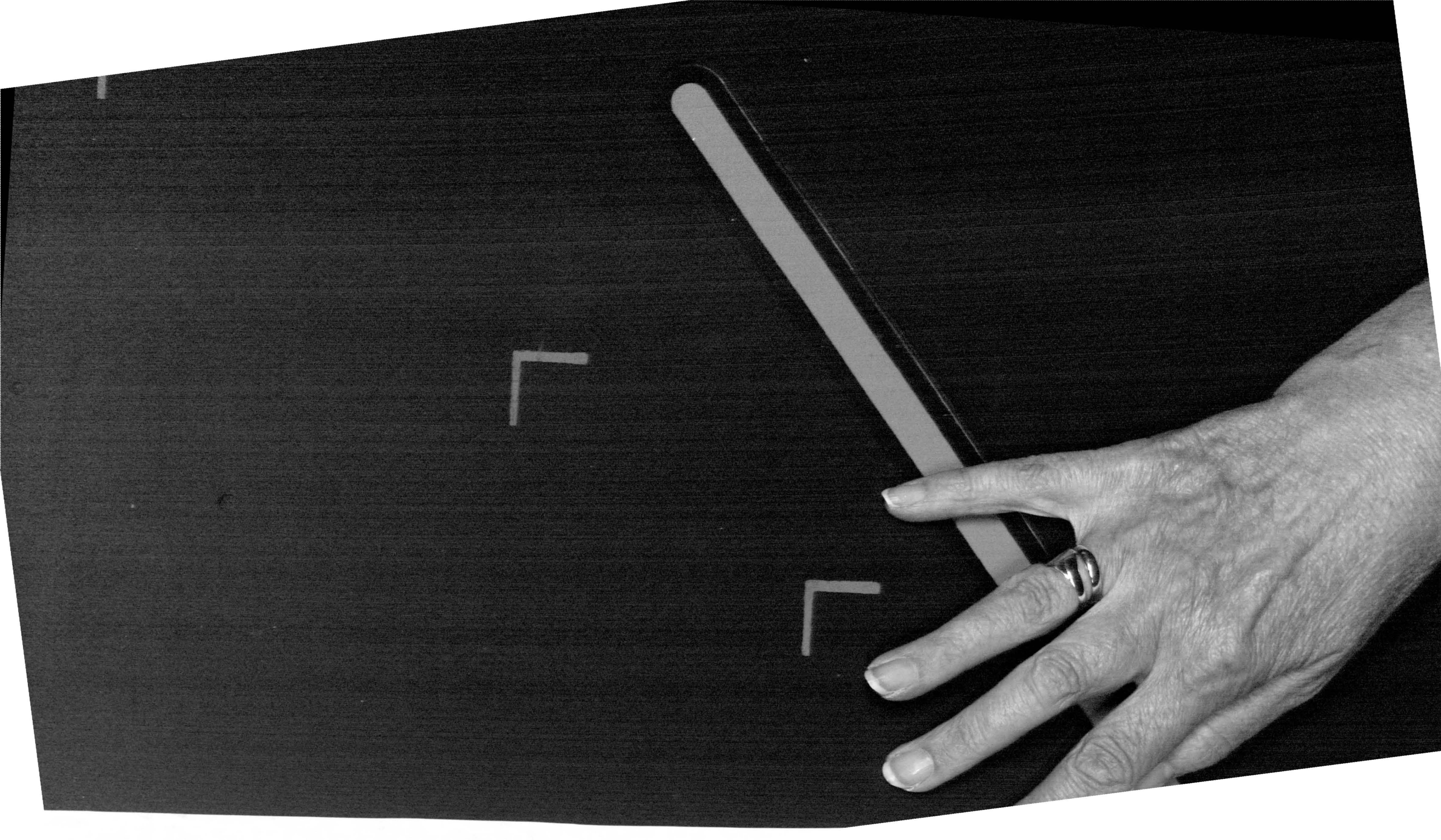


Fig.11.ix Predicted and Actual Weekly Nitrate Nitrogen Concentrations at Selected Stations.



distribution more nearly log-normal than normal does not imply that it should be assumed that the values of NO3-N predicted from a regression model should be log-normally distributed. There are other factors to be considered. It is noticeable that in the absence of sewage effects the positive skewness of distributions generally increases downstream. Exceptions are between stations 28 and 29, the site of a lake, and 24 and 25 where the distributions become less skewed, though not significantly so.

The question arises whether the distribution of NO3-N values approaches normal as basin size decreases, and a second question is implied, ie. if a set of small basins has a set of normally distributed values does a composite basin have log-normally distributed ones?

The smaller sub-basins (1, 2, 12, 14, 17, 20, 23, 27, 31) generally have lower positive skewness but there are exceptions. Station 27 has a high positive skew. This receives spring flows from the Chalk at South Harting. An inspection of the frequency distributions of NO3-N at spring sites shows that positive skew is found only at those sites experiencing a preponderence of very low values. Otherwise an absence of positive skew is found. Similarly the field drain sites show approximate normal distributions except where mean values approach zero.

For each station the regression model gives eight mean values, therefore the question of distributions refers to that about these means rather than the overall mean. If the entire distribution for a station is disintegrated (Fig. 11 iii) it can be seen that the log-normal

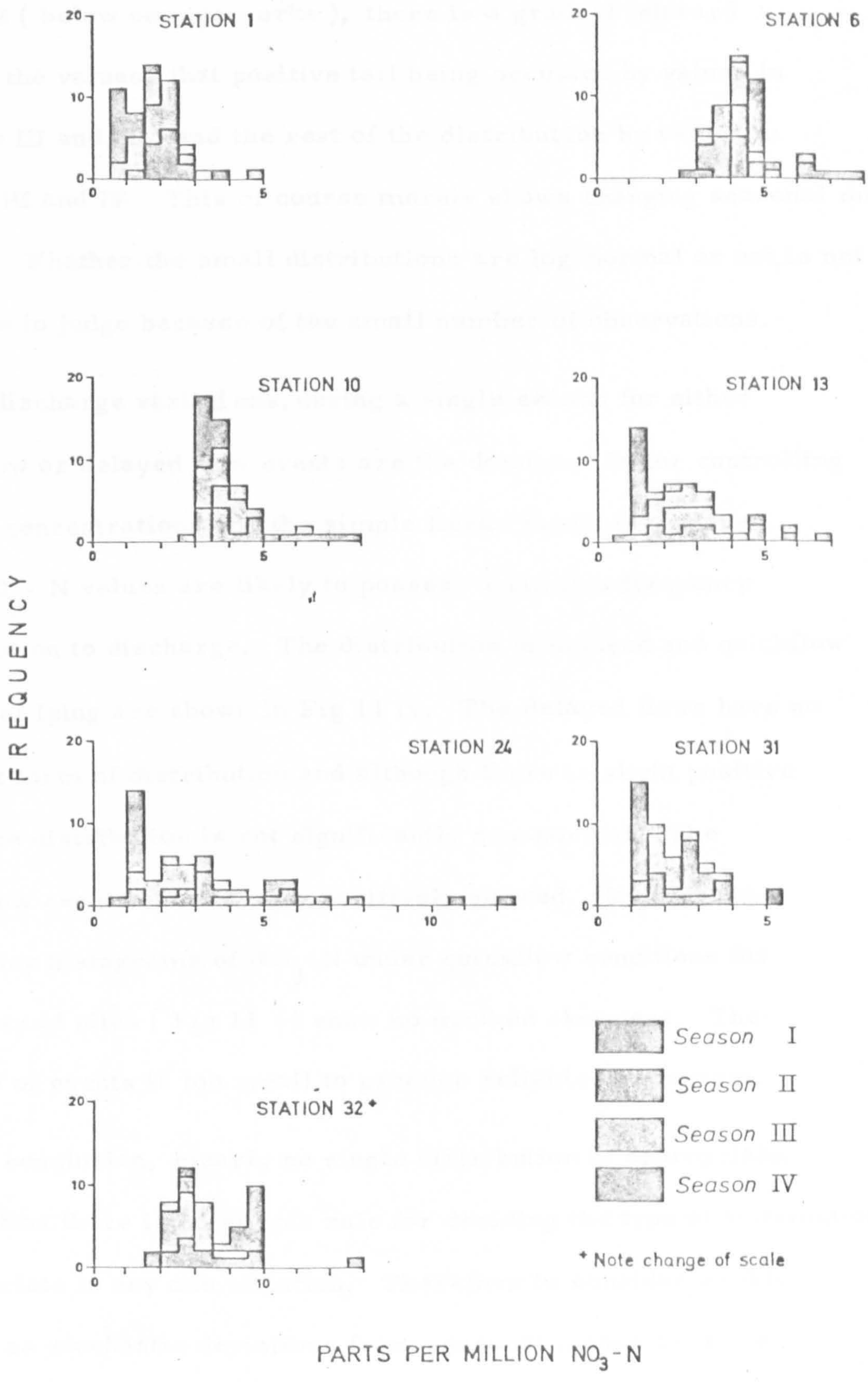


Fig. 11.iii Seasonal Frequency Distribution of Nitrate Nitrogen Concentrations Observed at Selected Stations on the Main River and Tributaries.

distribution at some sites consists of parts which have no distinct log-normality. The disintegration shows that except at sites 6 and 32 (below sewage works), there is a gradual leftward shift in the values, that positive tail being occupied by values in seasons III and II, and the rest of the distribution by values in season III and IV. This of course merely shows changing seasonal mean values. Whether the small distributions are log-normal or not, is not possible to judge because of the small number of observations.

If discharge variations, during a single season for either quickflow or delayed flow events are the dominant factor controlling NO_3-N concentrations and the simple linear model is assumed then NO_3- N values are likely to possess a similar frequency distribution to discharge. The distribution of delayed and quickflow events at Iping are shown in Fig 11 iv. The delayed flows have no distinct form of distribution and although there is slight positive skew the distribution is not significantly non-normal. The quickflow events are strongly positively skewed. However, the frequency histograms of NO_3-N under quickflow conditions for a variety of sites (Fig 11 v) show no marked skewness. The sample of events is too small to produce reliable parameters.

In conclusion, clearly no single distribution is appropriate. In addition there is no simple rule for deciding the type of distribution appropriate to any one situation. Therefore to consider weekly values as stochastic deviations from seasonal means would be inappropriate, first because the distributions cannot be specified and secondly because there is no valid statistical model available which will cope with a variety of error forms even if they could

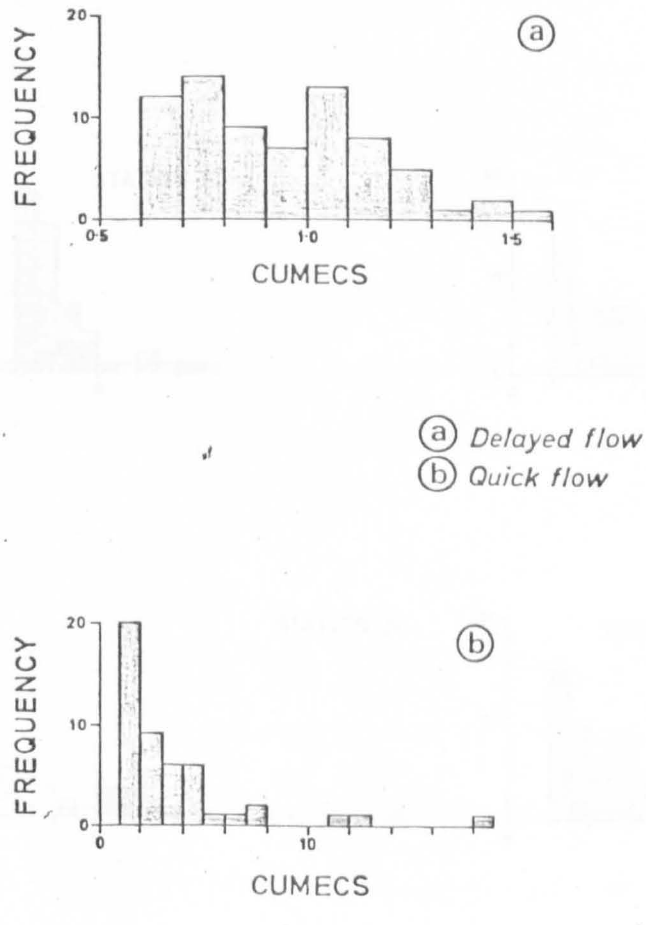


Fig. 11.iv Frequency Distributions of Systematically Sampled Discharge Measurements for Delayed Flow and Quick Flow Events at Iping Mill, 1972 - 3.

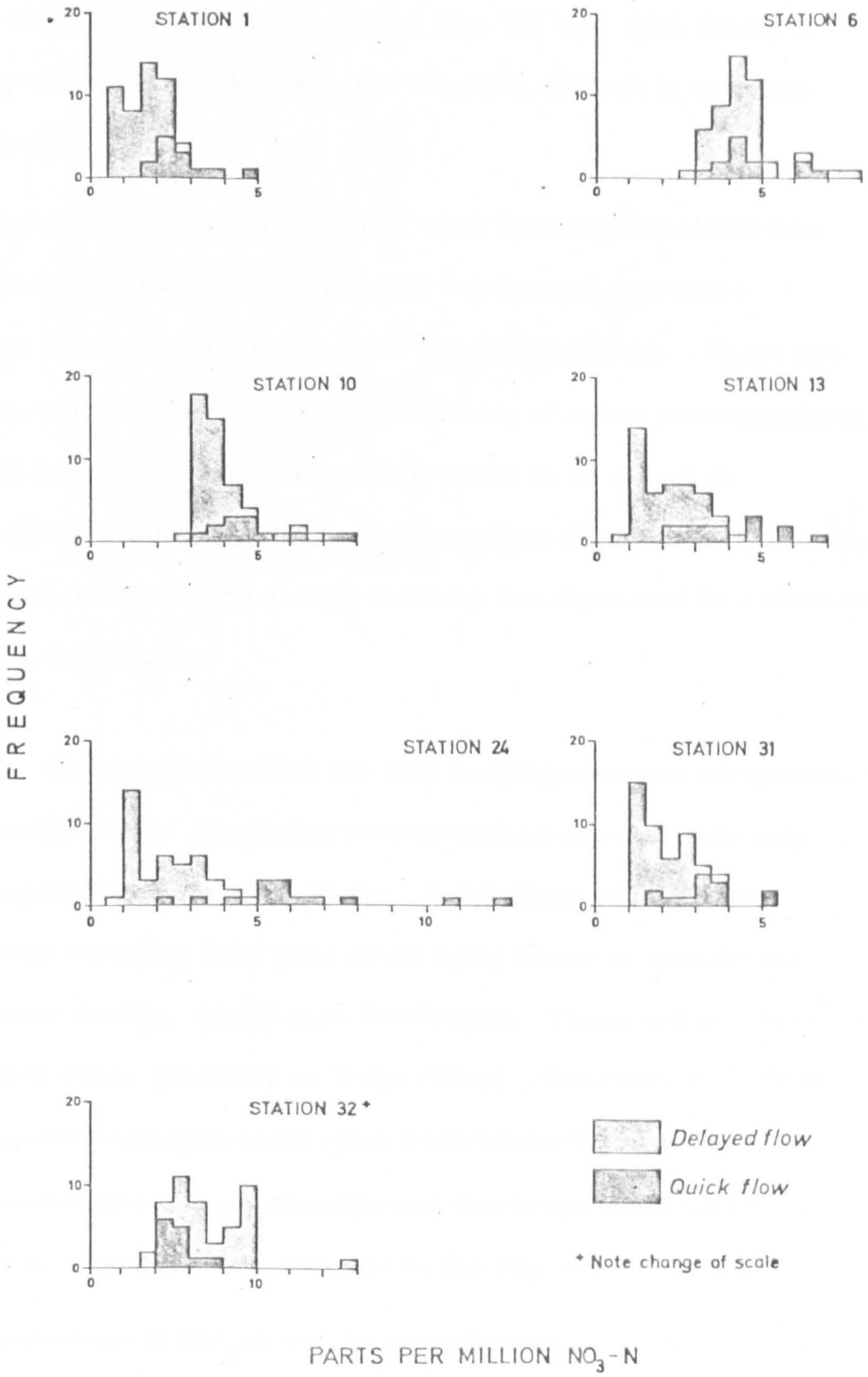


Fig.11. v Frequency Distributions of Nitrate Nitrogen Concentrations at Selected Stations on the Main River and Tributaries for Both Discharge States.

be defined. Further a regression model using a simple estimate for prediction does not take account of the change of standard error with distance from the mean (Fig. 11 vi). With discrete dummy variables which interact it becomes difficult to estimate this change.

Heretofore, the distribution of most hydrological events has been assumed to be normal or log-normal or a more complex function such as Pearsons Type III for floods. There has been very little attention to the distribution of solute concentrations. As with floods, however, " intuitively there is no reason to expect that a simple distribution will apply to all streams" (Linsley, et al 1975, p. 342). Further it is unlikely that there will be a markedly superior distribution.

ii) Discharge provides the only useful parameter which varies on a weekly basis. Discharge measurements are available only for Iping at the mouth of the basin. Predictions of most water chemistry variables have been made using linear or curvilinear regression models, based upon discharges. These are successful at individual sites, generally on large rivers. However, it is clear that even if discharges at all sites were known there would be no consistent or general relationship and discharge could not easily be used as an independent variable in the regression model.

Predictions of NO_3-N can be made however, by assuming that

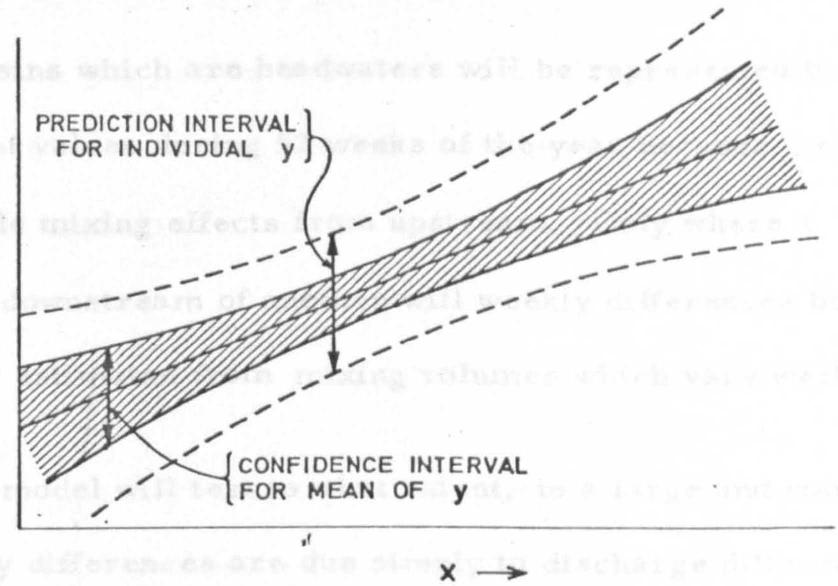


Fig. 11.vi Interval Estimate for the Mean of Dependent Variable (y) and Prediction Interval for Individual y.

the seasonal mean NO3-N value holds for discharges from each sub-basin for each week with a particular discharge state. These are used in making estimates of weekly values of NO3-N concentration at stations throughout the basin by using a mixing model with weekly discharge values.

Sub-basins which are headwaters will be represented by only eight different values during 52 weeks of the year because they do not include mixing effects from upstream. Only where a sub-basin is downstream of another will weekly differences be shown, being estimated from mixing volumes which vary weekly.

Such a model will test to what extent, in a large and complex basin, weekly differences are due simply to discharge differences from various parts of the basin. NO3-N concentrations in source waters are assumed to vary only with discharge state. If such a model is successful, ie. the dependence of NO3-N values on continuously varying discharge can be ignored, then predictive models of NO3-N may be developed which use discharge estimates in the mixing part derived from models which have already proved successful. In other words, conventional basin discharge models which are of the distributed parameter type may be extended to provide predictions of water quality in ungauged basins.

It is assumed that the weekly time scale is such that equal discharges will not be produced from equal areas in a lithologically variable basin. Therefore a method of estimating discharges from sub-basins on a weekly basis was devised taking account of their different characteristics. It was based on weekly discharge measurement at Iping and involved the distribution of this value to different parts of the basin.

For the various reaches in the basin concentration of NO_3-N at the upstream and downstream limits were known. Concentrations in the water draining the reach from the intervening sub-basin can be calculated using:

$$c_3 v_3 = c_2 v_2 + c_1 v_1$$

where,

c_3 = concentration of NO_3-N at downstream station

c_2 = concentration of NO_3-N at upstream station

c_1 = concentration of NO_3-N in water from sub-basin

v_3 = volume of water at downstream station

v_2 = volume of water at upstream station

v_1 = volume of water from the sub-basin

Then,

$$c_1 = \frac{c_3 v_3 - c_2 v_2}{v_1}$$

$$v_3 = v_2 + v_1$$

for steady conditions, which are assumed.

c_1 is the dependent variable in the model

c_2 and c_3 are available from the sampling programme

v_1, v_2, and v_3 were not measured.

INSERT.

Therefore a discharge model was devised to provide estimates of discharge from each of the sub-basins. Discharges were estimated for weekly periods. The only measurements of discharge in the basin were at the mouth, Iping. The problem then was to distribute the flow at Iping for weekly intervals to each part of the basin. This was done in proportion to the area of each sub-basin but account was taken of the volumes of quickflow and delayed flow at Iping and the relative responses of each rock type in terms of the proportion of flow which it produced as quickflow.

Quickflow was considered to be the discharge contributing to the peaks of the hydrograph at Iping (Fig. 11 vii). It is difficult to be precise about what constitutes quickflow. Various methods of hydrograph separation have been proposed (Gregory and Walling, 1973) but they produce very similar results and are generally empirical. The separation time for any particular event for this analysis was drawn from the point of the hydrograph rise to a point on the recession limb. Selection of the latter was based upon inspection for changes in curvature (Fig 11 viii). Where successive hydrograph peaks coalesced the quickflow separation time was taken as a smooth curve joining the successive troughs (Fig. 11viii B).

The model produced estimates of the total yield of water (q_{kj}) incorporating both quickflow (q^A_{kj}) and delayed flow (q^B_{kj}) for k lithologies over j weeks. The total flow at Iping (Q) was distributed for the whole year in proportion to the area of each lithology (A_k) ie. net precipitation was assumed to be uniform and there were no storage effects.

Then:

$$Q^A = \sum_{k=1}^{n} Q \, (A_k / A) \cdot \gamma_k \qquad \mathrm{I}$$

where,

Q^A is the total quickflow at Iping

A is the total area of the basin

γ_k is the proportion of discharge yielded as quickflow

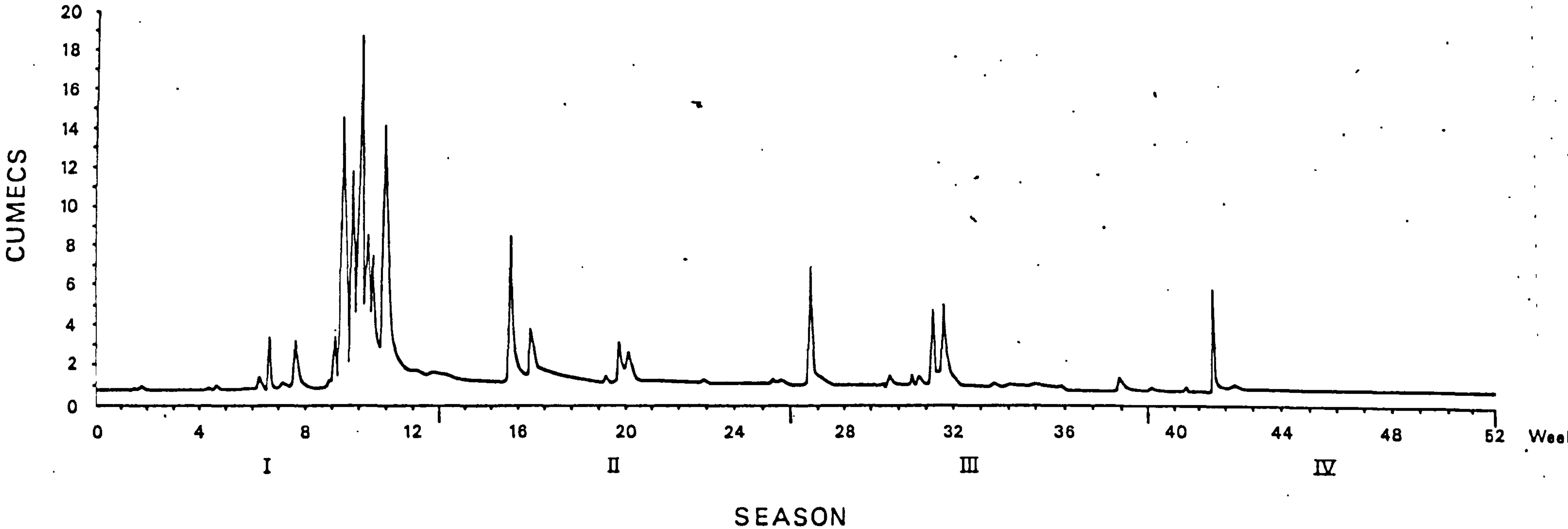


Fig. 11. vii Hydrograph at Iping 1972 - 3 (as Fig. 2. iii).

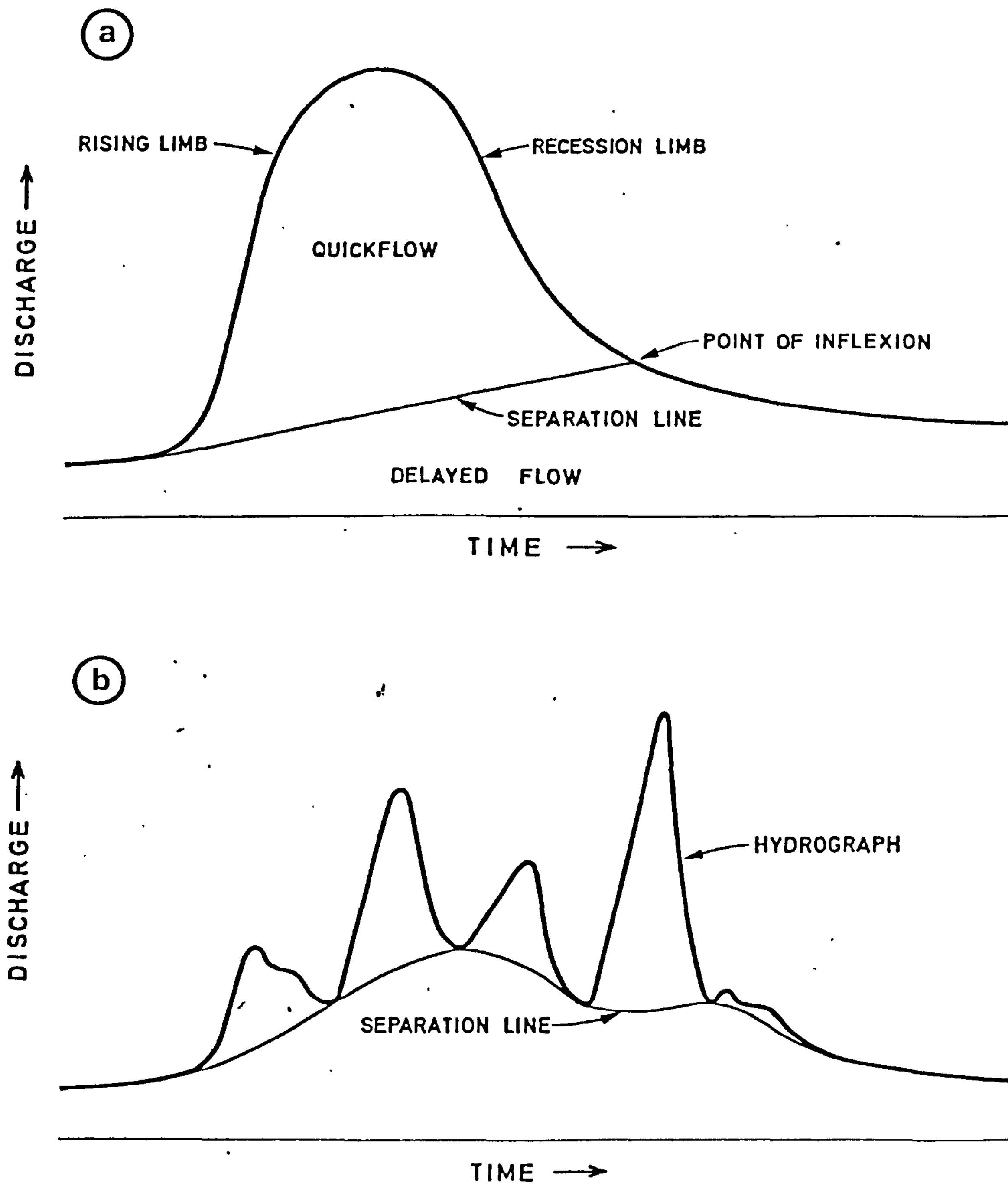


Fig. 11. viii (A) Baseflow Separation.

Fig. 11. viii (B) Baseflow Separation for Coalesced Peaks.

Similarly:

$$Q^B = \sum_{k=1}^{n} Q\ (A_k / A)\ .\ b_k \qquad \text{II}$$

for delayed flow.

Only the two sets of parameters γ_k and β_k are unknown ($\gamma_k = 1 - \beta_k$) and need to be estimated.

The quickflow response of areas on a particular lithology depends upon several factors. It depends upon the hydraulic conductivity of the soil, which in turn depends upon the grain size distribution of the soil as well as soil structure, the presence of vegetation and the water status in the soil. Quickflow response is also determined by topography and the presence of artificial drainage systems. It was not possible to produce estimates of γ_k and β_k from first principles because of the complexity of the problem.

The relative magnitude of quickflow responses were taken from general statements (Sussex River Authority, 1970) and the relative % clay in each soil type (Table 11 iii). The order is:

1.. Chalk
2. Lower Greensand
3. Upper Greensand
4. Weald Clay
5. Gault

Quickflow response increases from 1 to 5.

Then:

$$q_1^A + q_1^B = q_1$$

TABLE 11 iii

MECHANICAL ANALYSIS OF SOILS FROM EACH GEOLOGICAL DIVISION

(i) Based on information supplied by S. Nortcliffe and J. Hughes (KCL)

GEOLOGY	Chalk	Upper Greensand	Gault	Lower Greensand (hythe beds)
VEGETATION	Permanent Pasture	Permanent Pasture	Wood-land	Fallow
ANALYTICAL DATA				
pH	7.4	7.0	5.1	6.8
% organic	19.1	0.3	0.6	0.2
% N (Kjeldahl)	3.2	0.2	0.2	0.0
% sand	7.0	18.0	17.0	77.0
% silt	59.0	52.0	23.0	17.0
% clay	34.0	30.0	60.0	6.0

continued/...

TABLE 11iii(continued)

(ii) Based on information supplied by Fisons Ltd, - Levington Research Station.

GEOLOGY	Chalk	Upper Greensand	Gault	Lower Greensand (folkestone beds)	Lower Greensand (sandgate beds)	Lower Greensand (hythe beds)
VEGETATION	Permanent Pasture	Permanent Pasture	Perma-nent Pasture	Heathland	Permanent Pasture	Plantation
ANALYTICAL DATA						
pH	7.8	7.0	5.9	4.6	6.5	5.4
% organic	2.6	2.4	2.3	1.6	1.8	0.1
% sand	18.7	30.3	29.8	87.2	78.2	85.2
% silt	64.3	34.7	23.9	6.5	5.5	1.7
% clay	12.2	27.2	44.1	5.2	16.1	15.1

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$$q_5^A + q_5^B = q_5$$

and,

$$q_1^A + q_2^A + q_3^A + q_4^A + q_5^A = Q^A$$

$$q_1^B + q_2^B + q_3^B + q_4^B + q_5^B = Q^B$$

$q_1 \ldots\ldots q_5$ have been estimated on the basis of the initial assumptions. Q^A and Q^B are known. There are ten q^A and q^B values but only seven equations. However, there are inequalities which may be employed in order to provide estimates:

$$q_1^A < q_2^A < \ldots\ldots\ldots < q_5^A$$

$$q_k^A \neq Q_k^A$$

$$q_k^A \neq 0 \text{ , and in fact } q_k \text{ , } q_k \gg 0$$

As each rock type can be assumed to yield some quickflow or a substantial proportion of delayed flow. The overall quickflow response of the basin was 27% and so reason demanded that the lithology covering almost half of the basin (Lower Greensand) should not have a response too dissimilar from this figure. These equations and magnitudes provided a limited range of available values. Several sets were tried and none produced widely different values. It was not necessary to accept the estimated NO_3-N values differing by more than 0.5 ppm in the model.

Thus with the constraints of the inequalities the eventual computed NO_3- N concentrations did not appear sensitive to changes in quickflow response . The estimates of % quickflow from each lithology which were used in the model are presented in Table 11 iv.

The relative amounts of quickflow from each lithology (ψ_k) calculated from the yearly total were assumed to be constant during individual quickflow events.

$$\psi_k = \frac{Q. \ (A_k / A) \ . \ \Upsilon_k}{Q^A} = \text{a constant.}$$

Then the yield per unit area of quickflow from any particular lithology in a week is given by:

$$q_{kj}^A = \frac{Q_j^A \ . \ \psi_k}{A_k}$$

where Q_j^A is the total quickflow during week j.

Then the total quickflow from the sub-basin, 1, during week j (Q_{1j}) is given by:

$$Q_{1j} = \sum_{k=1}^{n} q_{kj} \ . \ A_{kl}$$

where A_{kl} is the area of basin l underlain by lithology k.

Similarly for delayed flow.

Having calculated the water yielded from each sub-basin

TABLE II: iv

ESTIMATED PER CENT QUICKFLOW FROM THE DIFFERENT GEOLOGICAL DIVISIONS.

Division	%
Chalk	10
Upper Greensand	25
Gault	60
Lower Greensand	15
Weald Clay	40

each week these volumes were routed through a network mixing model in order to calculate the concentrations at stations from NO_3-N concentrations estimated for the sub-basins.

Inputs from sewage works were also included. These were based upon weekly measurements of inputs at Petersfield. Inputs from other works were assumed to be the same proportion of this measured flow as given by the Sussex River Authority (1970). Concentrations were based upon measured values at Petersfield and Liss works. Values at Buriton were assumed the same as at Petersfield and at South Harting and Rogate the same as at Liss because of the similar types of works.

The 52 concentrations estimated for a selection of stations are presented in Table 11 v, with comparative values and a selection of frequency distirbutions in Fig. 11 ix. These have been chosen to show the sort of circumstances in which the model was unsuccessful.

Predicted values for Princes Bridge (station 16) are consistently higher than actual, except for week 8. The Coldhayes Stream is dominated by Gault and has a high % area in arable use (Table 9 iii). The regression model overemphasises this effect drastically and although the pattern of peaks and troughs coincide to a marked degree the mean values are very different. Other elements which are not reproduced in

TABLE 11 v

PREDICTED WEEKLY VALUES OF NITRATE NITROGEN CONCENTRATIONS AT SELECTED STATIONS ON THE MAIN RIVER AND ITS TRIBUTARIES.

Sequence of concentrations at station 3:

3.6	3.6	3.6	3.6	3.6	3.6	5.5	5.5	5.4	5.7
5.6	5.5	3.6	4.0	4.0	5.3	5.3	4.0	4.0	5.3
4.1	4.0	4.0	4.0	4.0	4.0	3.9	3.2	3.2	3.2
3.9	4.0	3.2	3.2	3.2	3.2	3.2	3.2	3.2	2.7
2.7	3.5	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
2.7	2.7								

Sequence of concentrations at station 6:

5.0	5.0	5.0	5.1	5.1	5.0	6.3	6.4	6.2	6.8
6.7	6.2	4.8	4.8	4.7	6.3	6.1	4.7	4.81	6.2
4.9	4.9	4.8	4.8	4.9	4.9	4.9	4.2	4.2	4.3
4.9	4.9	4.3	4.3	4.3	4.4	4.6	4.7	4.5	4.4
4.5	4.7	4.3	4.3	4.3	4.5	4.4	4.4	4.4	4.4
4.4	4.4								

Sequence of concentrations at station 10:

3.6	3.6	3.6	3.7	3.6	3.6	4.9	4.9	4.9	5.1
5.0	4.8	3.4	3.7	3.7	4.7	4.6	3.6	3.7	4.7
3.7	3.7	3.7	3.7	3.8	3.7	3.7	3.1	3.1	3.1
3.8	3.7	3.1	3.1	3.1	3.2	3.3	3.3	3.2	3.0
3.1	3.4	2.9	3.0	3.0	3.1	3.0	3.0	3.0	3.0
3.0	3.0								

/ cont.

TABLE 11 v

Sequence of concentrations at station 16:

12.8	12.8	12.8	12.8	12.8	12.8	17.8	18.0	16.8	18.9
18.8	17.7	13.4	12.5	12.1	17.3	16.8	12.3	12.1	1 .8
13.1	12.5	12.1	12.1	12.1	12.6	12.1	11.9	11.4	11.9
11.5	12.6	11.7	11.5	11.5	11.6	11.4	12.0	11.8	11.3
11.3	13.2	11.4	11.2	11.2	11.2	11.2	11.2	11.2	11.2
11.2	11.2								

Sequence of concentrations at station 30:

3.0	3.0	3.0	3.0	3.0	3.0	5.5	5.5	5.3	5.8
5.8	5.5	3.0	3.8	3.8	4.8	4.7	3.8	3.8	4.7
3.9	3.8	3.8	3.8	3.8	3.8	3.7	3.1	3.0	3.1
3.6	3.8	3.0	3.0	3.0	3.0	3.0	3.1	3.1	2.5
2.6	3.6	2.6	2.5	2.5	2.5	2.5	2.5	2.5	2.5
2.5	2.5								

Sequence of concentrations at station 34:

2.3	2.3	2.3	2.4	2.3	2.3	4.1	4.0	4.0	4.2
4.1	3.9	2.2	2.9	2.9	3.3	3.3	2.8	2.9	3.3
2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.3	2.3	2.3
2.9	2.8	2.3	2.3	2.3	2.3	2.5	2.4	2.4	2.1
2.1	2.8	2.0	2.1	2.1	2.2	2.1	2.1	2.1	2.1
2.1	2.1								

the predicted one; the gradual decline in values during the first few weeks, the marked trough during week 9, which seems perculiar to the Coldhayes Stream and may be an observational error; and the peak in week 27. This represents only a minor peak in discharge but being in early spring is probably some sort of flushing effect which the regression model has not picked up.

At Mizzards (station 30) the actual and predicted values are much closer. This represents conditions with no important effects from effluents or arable land use.

Predicted values are consistently higher than actual, except again during the first peak. A further difference between the data sets is after the first peak of week 8 when the actual values show a steady decline for six weeks. The predicted values, following the pattern of discharge changes show a plateau pattern. This with absence of decline in predicted values during weeks 1 to 6 and a peak in week 27, show the important changes in NO_3-N values <u>not</u> related to discharge changes which occur in actual streams.

The data for theSouth Downs station (34) shows the inability of the model to cope with stations affected by sewage inputs. The magnitude and variability, particularly during the dryer weeks are not reproduced at all.

Sites on the main river show a generally closer correspondence between actual and predicted values. Durford (station 6) and Iping (station 10) are affected by sewage inputs and show the discrepancy in weeks 1 to 6 which is shown at South Downs (station 34). They also show the discrepancies characteristic of streams not affected by sewage inputs, viz. the plateau of actual values in weeks 9 to 12 and the absence of a peak in week 27. At Durford and Iping a peak in week 35 is not reproduced in the predicted data.

In summary, there are several major components of the actual data set which are not well reproduced and these are most apparent at sites on tributary streams. In the main river most of the discrepencies are apparent but the deviations are not as large as for the tributaries.

This is judged to be a consequence of the fact that events in the main river are more closely related to discharge and this element of the model, having been measured continuously at Iping, is more accurately represented than the other elements. The differences between the stations, reflected in different predicted values and the broad changes in values show the success of the regression model but there still remain many elements of the data set which are not well reproduced, because of inaccuracies in this model. In particular, flushing effects and, gradual decline in values during long periods of steady flow are not accounted for. A most serious inaccuracy is in the prediction of sewage effects.

PART 12

SUMMARY

SUMMARY.

The principal problem to which this thesis is directed is the extent to which a limited amount of readily available information can be used to predict Nitrate Nitrogen concentrations in a river draining a rural watershed.

First, the factors controlling concentrations in drainage waters from various sources were considered through a review of the literature. A set of parameters were chosen which described the basin and which were measured as survey information. From this an initial set of hypotheses were presented about the relations between the parameters and concentrations.

The parameters were: Geological type, Land-use, Discharge State, and Season. Four geological types were represented in the basin: Chalk, Upper Greensand, Gault, and Lower Greensand. The two land-uses distinguished were arable and non-arable. The discharge states were delayed and quick flows. The four seasons were: October to December (I), January to March (II), April to June (III), and July to September (IV).

It was postulated that Nitrate Nitrogen concentrations in drainage waters will increase from areas of Lower Greensand to Chalk to Upper Greensand to Gault because of the increasing fine fraction in the soils which these lithological types support. Further, concentrations in drainage from arable land will be greater than in drainage from non-arable land. They will also be

higher during quidkflow events and higher during seasons I and II than during seasons III and IV.

At this stage neither the relative importance of the factors nor the existence of interactions between them could be specified because of the lack of comparative data relating to the conditions of the study. The relations between the four parameters and Nitrate Nitrogen concentrations in springs and field drains were tested on the assumption that these sources were the principal ones in rural watersheds. Sewage works were also considered an important source in particular parts of the catchment under study.

In considering Nitrate Nitrogen concentrations in water from springs the observations showed that:

1. The only significant factor affecting concentrations was the geological type, which accounted for the larger part of the variance.

2. There were no significant differences between the seasons or between discharge states.

3. Individual springs showed high concentrations during quickflow events but most showed little variation with either flow or season.

4. The magnitude of the mean concentrations for different lithologies varied not in relation to associated soil properties but in relation to % arable land use on each lithology. The effects of land -use differences could not be analysed further because of the uncertainty in defining the catchment area of a

spring.

Variations in Nitrate Nitrogen concentrations from field drains were examined in relation to all four factors. The observations showed that:

5. Each of the four parameters was significant in explaining the variance in Nitrate Nitrogen concentrations in field drainage; the interaction between land-use and geology was also significant.

6. Higher concentrations were associated with: quickflow events; arable land uses; areas on Gault (which supported soil with the highest proportion of fines in the study area); and season I.

7. The most important parameters were land-use and geology which together accounted for the larger part of the variance. The interaction effect between arable land-use on areas of Gault provided the highest values of Nitrate Nitrogen concentration.

8. Land-use was the single most important parameter, with arable sites having values consistantly twice as high as non-arable.

9. Individual sites showed a "flushing" effect during the first wet period of season I, particularly on the Upper Greensand.

10. Inputs to the river from sewage works varied according to the time of day and the year as well as the discharge state. Concentrations were independent of time of day but varied during the year year being higher during warmer months. During high discharge events concentrations fell markedly below those of low discharge events. A simple linear regression model against discharge and time of year accounted for most of the variance in Nitrate Nitrogen concentrations in sewage effluent.

The observations of Nitrate Nitrogen concentrations in springs and field drains showed that the initial hypotheses were corroborated. Further the comparative importance of the four parameters was established for both source types in terms of the proportion of explained variance, and the majority of the interactions were specified. Having tested the hypotheses with controlled observations they were then examined at a scale where complex effects could be assumed.

11. Relations between mean Nitrate Nitrogen values at sites on the drainage network and the four parameters were described by a regression model. A stepwise proceedure was used against a restricted set of the possible interactions. Only ten independant sub-basins out of the thirty six in the study area could be used, and for their eight associated mean values a regression model using only eight variables

accounted for over eighty per cent of the total variance.

12. These eight variables selected in the stepwise procedure showed that the same relations which held at the site scale also held at the sub-basin scale although different parameters and interactions were shown to have the major significance at this scale. Season and discharge state assumed greater importance.

13. The values of the associated regression coefficients in both sign and magnitude corroborated the conclusions from the controlled observations.

The regression model was then used in a predictive manner having been calibrated for ten of the thirty six sub-basins which made up the entire basin. It was assumed that over a long period equal areas of the basin would yield equal runoff, and a simple mixing model was proposed in order to estimate the mean Nitrate Nitrogen values at all thirty six stations on the drainage network. The model necessitated using additional information about sewage effluent concentrations and discharges.

14. The residuals from the predictive model showed that serious errors occurred with the basins which possessed high proportions of their area on Gault or possessed sewage works. No further information was available to reduce the second sort of error and the first appeared to be due to a biased sample of sub-basins used to calibrate the model as they were all in headwaters with low proportions of their area on Gault.

15. Using land-use and discharge data for the year 1976-8 a set of mean values was estimated for Iping Mill at the mouth of the basin, being the ultimate output from the model. These are compared with the mean values of the measured data. There are some limitations in the use of the measured data because of the infrequent and irregular sampling. The effects of reduced areas of arable land use on Gault is shown in the reduced mean values which correspond to the the lower measured values for that year. However, other factors such as changes in sewage management could account fot these effects and thus comparison with 1967-8 data does not provide a robust test of the model.

The prediction of weekly values required the addition of further information to the model. The use of probability distributions was judged to be unsatisfactory because of the lack of any generally acceptable probability function. A distributed runoff model was proposed which was based on weekly measurements of runoff at the mouth of the basin. This model also required information on the areas of each lithology in each sub-basin, the total quickflow and baseflow each week, and the proportion of total runoff from each lithology which went as quickflow. The first three parameters were measured and the fourth estimated. There must remain some doubt about the validity of these estimates which cannot be verified independently.

The runoff model is of a type which is not known to have been used before and therefore there are no independent runoff estimates available. A more conventional distributed runoff model is not known to have been applied either to the Rother, which is distinctly varied in lithology and has dominant groundwater effects, or to the sort of problem with which this thesis deals.

Weekly estimates of discharge for each sub-basin were made and these were employed in a simple mixing model as before to produce estimates of weekly Nitrate Nitrogen concentrations at thirty six sites in the basin.

16. The residuals which were apparent in the prediction of mean values were also apparent in the sets of weekly values. In addition the flushing effect was not reproduced nor were the gradual decline in Nitrate Nitrogen values through the periods of steady flow or through successive peaks of discharge.

17. The model appears to be most successful for streams whose basins contain a relatively small amount of arable land use on Gault and no sewage effects. This is hardly suprising since the variance of the values is controlled largely by these two factors.

The success of the model cannot be gauged on these criteria alone. Stations with high actual values also have high predicted ones and most of the peaks and major elements of the time changes are reproduced.

PART 13

CONCLUSIONS

CONCLUSIONS

i A simple statistical model for NO3-N values in runoff from a drainage basin has been developed which is based on readily available information about conditions in the basin.

ii Further, the model is consistent with a set of hypotheses relating to the processes controlling NO3-N supply in natural drainage.

iii These hypotheses are based on a literature review and confirmed by controlled observations at individual sites.

iv The statistical model of mean NO3-N values throughout a basin remains inaccurate because of biased calibration, inaccurate modelling of sewage inputs and the presence of specific effects such as a lake and a farm.

v The statistical model was successful in explaining a high proportion of the variance in mean NO3-N values and having coefficients and variables consistent with the hypothesised relations.

vi Extension to weekly data was problematical because the only time variable was season. This necessitated introducing a second model for runoff. Antecedence and flushing effects were not reproduced and the deficiencies of the previous model were retained.

vii The main factors controlling high NO3-N concentrations in the Rother basin are:

a. high per cent area with heavy soil

b. high per cent area in arable land use

c. the particular effect of arable use on Gault

d. flushing effects after long dry spells

e. leaching during late Autumn and early Winter

f. the presence of sewage effluents

viii This thesis has explored the feasibility of predicting river NO_3-N concentrations from simple survey information about its basin. Recognising that a more physically based approach is unlikely to be feasible at the large scale it has shown not only that a simple statistical model is successful in many respects, but also that the physical relations implied by the use of particular independent variables do in fact hold and that the coefficients in the model are consistent with these relations.

ix There are serious limitations in the use of this particular model and this sort of model in general. Primarily the calibration only applies to one set of conditions. The factors controlling NO_3-N concentrations are very dependent on climate and soil moisture conditions and the year of study, as any single year must be, unrepresentitive. Further, the model can only apply to one basin. Very many types of soil and land-use are not represented. But the hypothetical relations and the conclusions of the analysis of site data probably have general validity for the sorts of conditions which they represent.

PART 14

REMAINING WORK

REMAINING WORK

The type of model developed in this thesis applies to a particular scale of drainage basin and is constrained specifically by the sorts of independent data which can be used in it. It is meant to be applied to river basins for which geological and land use surveys exist (or can easily be carried out) and for which there are flow records.

Other information is needed on the discharge volumes and NO_3-N concentrations of sewage effluents and the hydrological response of the different lithologies.

Further work on the modelling of NO_3-N in rivers needs to be done in areas other than the one to which this thesis applies. The sort of problem to which this model is meant to apply is that which the water resource manager or water quality engineer faces when confronted with limited data and time. Before such a model could be applied however, deficiencies must be overcome. These can be regarded as problems of applicability and problems of calibration. The former are the more critical at this stage.

The regression part of the model fails to reproduce effects which last less than a season because the only independent time parameter is season.

In operating this model in conjunction with a weekly model of discharge the effects of flushing and antecedence, for example, could be incorporated. However, longer runs of data would be required for calibration because their occurrence depends on the coincidence of two or more factors.

The regression model applies only to a very limited number of lithologies, although these represent a very wide range of soil conditions and hydrological characteristics. Observations of many other sorts of soil types and different land-uses along with climatic effects are required:

a. to test the wider validity of the initial hypotheses, and

b. to test whether the model applies elsewhere in the same form.

The year of study was one of very low rainfall. Therefore, only a limited set of runoff conditions and time sequences of events were represented. The effect of the occurrence of high rainfall in season III and IV for instance needs to be observed, as well as the effects of combinations of successive storm peaks.

Effects such as farm effluents appear to be unimportant to the NO_3-N levels except at specific localities and it is probably safe to assume that because the total volumes of water coming from such sources are relatively small the effects must be small too. The presence of lakes is not insignificant, however. Only one small lake was represented in the study area and this produced serious anomalies in predicted values. The effects of lakes needs to be incorporated into the model though it is not possible to specify new independent parameters which may be successful.

This thesis has completely ignored the question of uptake by plants and animals in rivers rather than lakes. Owens (1970) suggests anomalies in inputs and outputs to rivers are accounted for by these processes but his conclusions are unsubstantiated. The phenomenon does deserve attention, though in this study no pattern of residuals suggest that uptake is operating significantly.

A concept which has found application in the develop ment of runoff models which probably extends to solutes is that of contributing area. If storm runoff comes preferentially from certain areas within the basin then NO_3-N in storm runoff must also, with the additional conditions that the rate of NO_3-N supply will depend on the geology and land-use characteristics and season. It should be possible to specify weighting functions within a regression model based upon this concept which may provide improved estimates particularly for small rainfall events or those in drier seasons.

Problems of calibration which remain to be resolved and for which additional independent data is needed for this particular study are:

a. Improved estimates of sewage inputs and NO_3-N concentrations.

b. Evaluation of a more represent tive set of sub-basins in terms of % area in arable land-use on Gault.

c. Better theoretical or experimental estimates of % quickflow - % baseflow from each lithology.

d. A more realistic hydrological model which takes account of time of sampling in relation to movement of waves of NO_3-N from sewage effluents and seasonal changes in relative hydrological response of the different lithologies.

APPENDIX 1

FERTILISER DATA SUMMARY

SUMMARY OF FERTILISER DATA.

Geology	Land Use	Application-Units 1972-1973.
Chalk	Arable	60-90
	Pasture	100-350
Upper Greensand	Arable	60-95
	Pasture	100-350
Gault	Arable	80
	Pasture	120-400
Lower Greensand	Arable	60-85
	Pasture	100-400

Pasture - fertiliser applications with intensive stocking.
Arable - spring barley fertiliser applications.

APPENDIX 2

DATA SET

MAIN RIVER WEEKLY SAMPLES

	1972 Oct 3rd	Oct 10th	Oct 17th	Oct 24th	Oct 31st	Nov 7th	Nov 14th	Nov 21st	Nov 28th	Dec 5th	Dec 12th	Dec 19th	Dec 26th	1973 Jan 2nd	Jan 9th
Greatham Stream	2.2	2.5	2.0	2.2	1.8	1.7	2.1	3.9	1.5	2.5	2.4	2.4	1.9	1.9*	1.6
Hawkley Stream	5.2	4.8	4.4	3.9	3.1	2.6	5.2	8.4	3.5	4.0	4.2	3.6	3.3	3.1	2.6
Liss	3.6	3.5	3.2	2.8	2.3	1.8	2.8	5.3	2.2	3.1	3.3	3.0	2.4	2.7	2.2
Prince's Bridge	5.7	5.4	5.9	3.6	3.4	3.6	3.7	5.6	3.7	4.0	4.0	3.7	3.1	3.3	3.0
Sheet	5.0	5.1	4.8	3.2	2.6	2.8	4.0	5.7	3.0	4.5	4.5	3.7	2.6	3.0	2.6
Durford	7.2	6.4	7.5	2.7	4.6	4.4	6.0	6.7	4.3	4.0	4.3	4.3	3.0	3.8	3.4
Habin	5.5	5.4	4.5	3.5	3.4	3.0	5.7	6.8	3.7	4.0	4.3	4.4	3.2	3.6	3.2
Terwick	6.0	5.9	5.6	3.6	3.3	3.4	7.0	6.5	4.4	4.2	4.4	4.6	3.6	3.6	3.4
Chithurst	6.1	6.6	6.3	4.1	4.4	3.8	7.1	7.5	4.2	4.2	4.2	4.9	3.4	3.7	3.5
Hammer	3.5	4.0	3.2	2.3	2.0	2.8	6.0	6.8	3.7	4.6	4.7	4.5	3.5	3.5	3.0
Iping	6.1	6.7	5.6	3.9	3.7	3.7	7.0	7.6	4.5	4.5	4.4	4.5	3.7	3.7	3.3
Barefoots	3.3	4.3	2.3	1.6	1.3	0.8	3.7	4.2	2.6	3.9	4.3	3.5	2.7	2.7	2.4
A 325	1.9	2.5	1.8	1.2	2.7	0.9	3.2	4.8	2.3	4.8	5.5	3.9	3.0	3.0	2.3
Coldhays	2.9	4.1	1.8	1.1	1.6	0.7	4.0	5.0	2.5	5.0	4.8	5.0	4.5	5.2	4.4
Flexcombe	5.5	4.8	1.6	0.5	3.4	3.5	20.0	27.5	11.0	13.0	12.0	9.4	6.6	7.3	6.0
Prince's Bridge	3.7	2.8	3.5	4.0	2.8	0.6	12.4	22.7	5.3	13.7	11.8	8.0	4.8	5.6	4.2
Roke	2.6	2.7	2.4	1.6	1.8	1.5	2.6	3.4	2.1	3.3	3.5	2.5	2.0	2.2	1.9
Harrow	3.5	3.7	3.0	2.0	2.3	2.2	3.9	6.8	2.6	4.6	5.1	3.1	2.3	2.6	2.2
Mill Lane	2.7	3.6	3.2	2.1	2.5	2.2	4.4	7.4	2.6	4.6	5.2	3.0	2.2	2.5	2.2
Berelands	0.7	0.5	0.5	0.7	0.6	0.7	10.4	9.1	4.9	4.2	3.5	5.0	5.2	4.9	9.3

* estimated value

MAIN RIVER WEEKLY SAMPLES

	1972 Oct 3rd	Oct 10th	Oct 17th	Oct 24th	Oct 31st	Nov 7th	Nov 14th	Nov 21st	Nov 28th	Dec 5th	Dec 12th	Dec 19th	Dec 26th	1973 Jan 2nd	Jan 9th
Frenchman's Lane	2.7	1.9	2.7	1.2	2.5	3.2	4.6	3.6	2.0	3.0	4.0	3.4	3.6	3.7	2.6
B 2146	2.3	1.9	1.2	1.1	2.3	1.2	1.9	3.6	3.0	3.3	3.4	4.0	3.2	3.9	2.0
Stroud	1.9	1.9	1.5	0.5	1.0	0.7	2.7	3.9	1.9	2.4	2.9	3.0	2.8	3.0	2.7
Borough Road	1.0	2.8	1.3	0.4	2.3	2.5	12.4	10.9	5.9	5.0	5.5	4.2	3.5	3.8	3.3
A 3	0.9	0.8	1.0	0.8	1.8	1.6	12.0	10.2	5.5	4.6	5.0	4.3	3.5	3.7	3.3
Stanbridge	10.5	5.3	10.2	6.5	3.2	4.9	12.4	9.2	5.5	4.2	4.7	4.5	3.8	4.0	3.6
Torberry	0.7	0.5	0.5	0.7	0.6	0.7	13.5	12.0	6.7	5.0	6.9	3.9	2.5	2.5	2.3
Goose Green	3.2	3.2	2.3	1.7	1.4	1.6	2.3	7.0	3.5	4.1	4.6	3.1	2.7	2.7	2.4
Parks Bridge	2.2	2.3	2.0	1.4	1.2	1.7	6.8	7.4	4.5	4.1	4.4	3.3	2.7	2.6	2.3
Mizzard's	4.0	3.9	3.5	2.3	2.5	2.1	10.9	8.0	5.1	4.4	4.0	3.8	2.8	2.4	2.5
South Harting	1.6	1.6	1.3	2.3	1.9	1.7	5.0	5.1	3.8	3.2	3.5	3.6	2.9	2.9	2.6
Week's Common	15.1	9.0	7.4	9.8	6.5	8.6	5.3	5.8	6.0	5.0	4.8	4.5	4.1	4.4	3.9
New Barn	12.0	9.4	8.6	4.3	5.9	5.6	9.1	5.9	6.0	4.6	3.4	4.5	3.9	4.0	3.7
South Downs	13.8	10.6	9.8	6.1	5.8	5.4	8.6	5.9	5.7	4.3	3.1	4.4	3.8	4.2	3.9
Dumpford Park	8.7	6.6	7.0	5.4	0.8	2.8	18.6	20.2	9.2	7.0	6.7	6.8	5.8	6.4	6.0
Goldrings	14.0	13.8	11.2	6.5	7.4	8.9	10.0	15.4	10.0	10.7	12.0	13.8	10.7	10.8	10.4

MAIN RIVER WEEKLY SAMPLES

	Jan 16th	Jan 23rd	Jan 30th	Feb 6th	Feb 13th	Feb 20th	Feb 27th	Mar 6th	Mar 13th	Mar 20th	Mar 27th	Apr 3rd	Apr 10th	Apr 17th	Apr 24th
Greatham Stream	2.7	2.2	2.4	2.2	2.3	2.0	2.1	1.9	1.5	1.6	1.3	4.5	1.9	1.6	1.4
Hawkley Stream	4.2	3.7	3.4	3.6	3.9	3.7	3.4	3.2	2.7	2.9	2.3	4.0	3.8	2.9	2.9
Liss	3.4	2.9	3.0	2.9	3.3	3.2	3.0	2.7	2.2	2.4	2.0	4.5	2.9	2.0	2.2
Prince's Bridge	3.6	3.4	3.4	3.6	3.9	3.9	4.1	3.4	3.0	2.7	3.4	5.0	3.9	3.2	3.1
Sheet	4.1	3.6	3.0	3.1	4.1	3.6	3.3	2.9	2.7	2.6	2.7	5.5	2.9	2.6	2.7
Durford	4.5	3.7	3.7	4.1	4.5	4.2	4.4	3.8	3.4	3.8	3.4	6.0	4.4	3.4	3.8
Habin	4.9	3.9	3.6	3.6	4.2	4.2	4.5	3.6	2.8	3.3	3.4	5.7	4.1	2.8	3.2
Terwick	4.8	4.1	3.6	3.8	4.2	4.2	4.7	3.5	3.0	3.2	3.7	5.3	4.4	2.8	3.3
Chithurst	4.5	4.0	3.6	4.2	4.4	4.5	3.8	3.7	3.2	3.4	3.3	6.2	4.1	2.8	3.3
Hammer	5.4	4.3	3.6	3.7	3.8	4.6	3.5	3.2	2.9	2.7	2.2	4.2	3.5	2.2	2.2
Iping	5.0	4.1	3.6	4.0	4.2	4.7	4.4	3.7	3.3	3.4	3.4	6.0	4.3	2.5	3.0
Barefoots	4.1	3.5	2.8	3.0	3.5	3.4	4.0*	2.8	2.9	2.6	2.8	4.6	3.4	2.2	2.4
A 325	6.7	4.7	3.0	3.5	5.1	4.0	3.6	2.7	2.3	2.0*	2.8	5.9	3.4	2.0	2.5
Coldhays	5.4	4.4	4.3	5.1	4.6	5.3	4.6	4.2	4.4	4.2	3.6	5.0	4.5	3.5	3.4
Flexcombe	12.0	10.8	7.7	4.7	12.1	9.7	7.4	6.6	5.0	5.1	3.9	10.8	6.8	4.0	4.6
Prince's Bridge	10.5	9.5	6.0	6.1	10.8	7.8	5.0	4.9	3.6	3.3	3.9	9.4	5.0	3.8	3.7
Roke	2.6	2.7	2.3	2.5	2.6	3.9	2.3	2.8	2.0	1.9	1.8	2.6	2.5	1.8	2.1
Harrow	3.4	3.2	2.6	2.7	3.4	3.2	2.6	2.5	2.2	2.2	2.5	4.6	2.8	2.0	2.5
Mill Lane	3.4	3.4	2.4	2.7	3.8	3.2	2.5	2.6	2.7	2.2	1.9	4.6	2.9	1.9	2.4
Berelands	6.7	3.4	4.3	10.8	5.4	5.0	9.1	6.7	7.4	8.5	7.2	5.4	6.7	9.6	8.4
Frenchman's Lane	4.4	3.0	3.2	4.7	3.6	3.5	4.1	2.9	2.5	2.5	2.9	5.1	2.8	2.2	2.1
B 2146	3.5	2.9	2.5	2.8	3.2	2.7	3.5	2.7	1.6	1.9	2.1	5.0	2.8	2.1	2.1

MAIN RIVER WEEKLY SAMPLES

	Jan 16th	Jan 23rd	Jan 30th	Feb 6th	Feb 13th	Feb 20th	Feb 27th	Mar 6th	Mar 13th	Mar 20th	Mar 27th	Apr 3rd	Apr 10th	Apr 17th	Apr 24th
Stroud	3.4	3.0	2.8	3.2	2.4	3.3	3.9	2.9	2.6	2.3	2.5	2.9	2.7	1.8	2.2
Borough Road	6.8	5.4	3.7	5.5	5.3	4.7	4.4	3.3	3.0	2.1	3.3	6.0	3.5	1.8	2.6
A 3	5.7	5.0	3.9	4.0	5.4	4.8	3.6	3.2	2.7	2.1	3.1	5.9	3.6	1.5	2.5
Stanbridge	5.4	4.9	4.0	4.4	5.2	5.2	3.8	4.0	3.2	3.0	3.4	6.2	4.1	2.6	3.2
Torberry	4.9	3.8	2.2	2.5	6.6	2.9	1.9	2.3	1.5	1.5	0.9	6.3	1.8	0.5	-dry
Goose Green	3.9	3.2	2.5	2.9	2.9	3.2	2.5	2.7	2.4	2.2	2.0	2.9	2.6	1.7	2.3
Parks Bridge	4.6	3.4	2.4	2.7	2.8	3.2	2.3	2.3	2.4	1.8	1.7	2.6	2.1	1.3	1.5
Mizzards	4.8	3.6	2.5	3.0	2.9	3.4	2.4	2.2	2.0	1.9	1.8	3.0	2.3	1.3	1.5
South Harting	3.4	3.0	2.7	3.5	3.0	3.4	2.5	2.9	2.6	2.7	2.1	2.8	3.0	1.7	2.1
Weeks Common	5.5	4.5	4.3	5.2	4.6	5.7	5.2	4.9	5.0	3.8	5.5	4.1	6.8	6.5	6.2
New Barn	4.2	3.7	3.9	4.7	3.4	5.0	4.6	4.6	4.3	4.1	4.2	4.2	5.5	4.6	5.0
South Downs	4.3	3.8	4.0	5.1	3.5	5.2	4.6	4.6	4.0	4.4	4.2	4.3	6.3	5.6	6.4
Dumpford Park	8.2	6.7	6.5	6.3	6.5	7.3	6.3	5.8	5.7	5.8	4.9	6.6	6.8	5.3	5.0
Goldrings	16.1	11.8	10.5	11.0	11.3	8.2	11.0	10.4	9.3	10.4	7.7	9.0	11.4	9.2	9.5

	MAIN RIVER							WEEKLY SAMPLES							
	May 1st	May 8th	May 15th	May 22nd	May 29th	Jun 5th	Jun 12th	Jun 19th	Jun 26th	Jul 3rd	Jul 10th	Jul 17th	Jul 24th	Jul 31st	Aug 7th
Greatham Stream	2.7	3.2	1.5	1.7	0.8	0.7	1.2	1.3	1.1	0.9	0.9	1.6	1.0	1.0	0.9
Hawkley Stream	3.2	3.2	3.1	3.0	3.4	2.7	3.9	4.1	4.2	4.3	5.2	4.2	4.4	4.5	4.7
Liss	2.7	2.9	2.4	2.2	2.4	2.0	2.4	2.5	2.35	2.2	2.4	2.4	2.5	2.0	2.2
Prince's Bridge	3.8	3.6	3.4	3.8	4.0	3.2	3.9*	3.6	3.35	3.1	3.4	3.3	3.5	3.1	3.5
Sheet	3.0	3.5	2.8	2.9	3.0	2.5	2.9	3.2	3.0	2.8	3.1	2.9	2.7	2.5	2.3
Durford	4.0	3.9	3.9	4.0	5.2	3.7	4.4	4.5	4.3	4.1	4.0	3.4	4.5	4.5	4.5
Habin	3.5	3.8	3.1	2.9	3.8	2.8	3.0	2.8	2.75	2.7	2.9	3.6	3.1	3.4	3.0
Terwick	3.5	3.8	3.3	2.8	3.7	3.0	3.6*	3.5	3.45	3.4	3.6	3.5	3.3	3.0	3.0
Chithurst	3.8	3.2	3.6	3.6	3.8	3.2	4.2*	3.8	3.75	3.7	3.7	3.9	3.7	3.4	3.8
Hammer	2.0	3.7	2.5	2.8	1.8	1.2	1.3	1.1	1.4	1.7	1.6	1.6	1.6	1.6	1.6
Iping	3.2	3.9	3.3	3.0	3.5	3.2	4.0	3.6	3.6	3.6	3.4	3.7	3.8	3.4	3.6
Barefoots	2.4	2.5	2.5	2.2	2.6	2.1	2.6	2.3	2.15	2.0	1.9	2.6	2.0	2.0	1.9
A 325	2.5	3.3	2.6	1.8	2.1	1.5	1.6	1.4	1.3	1.2	1.1	2.0	1.5	1.3	1.1
Coldhays	2.8	3.8	3.7	3.2	3.6	3.1	4.0*	3.7	3.55	3.4	3.3	3.8	3.4	3.3	3.1
Flexcombe	4.9	7.8	5.3	3.2	4.4	3.6	4.5	4.4	4.25	4.1	3.6	5.3	3.7	3.4	3.9
Prince's Bridge	3.7	6.4	3.8	3.6	3.2	2.5	1.8	1.7	1.55	1.4	1.4	3.0	1.0	2.1	2.0
Roke	1.9	2.4	1.8	1.8	2.2	1.7	1.9	1.7	1.65	1.6	1.7	2.0	1.8	1.5	1.3
Harrow	2.2	2.7	2.2	2.1	2.4	2.0	2.0	2.1	2.05	2.0	2.2	2.3	2.6	2.3	2.0
Mill Lane	2.2	2.6	2.2	2.0	2.3	1.9	2.1	2.1	2.05	2.0	2.1	2.3	2.3	2.1	2.1
Berelands	10.8	3.9	7.2	9.9	10.3	14.4	7.6	9.2	8.6	7.4	7.9	9.5	8.6	9.0	10.1
Frenchman's Lane	2.4	2.4	2.5	4.4	2.5	1.2	1.4	0.9	0.95	1.0	1.0	6.4	2.3	2.5	1.8
B 2146	1.9	2.5	2.2	3.4	2.1	2.0	1.7	1.7	1.85	2.0	1.8	3.7	1.9	2.5	2.0
Stroud	1.7	2.2	2.0	1.7	2.0	2.1	1.3	1.2	1.2	1.2	1.3	2.4	1.5	1.2	1.1

MAIN RIVER WEEKLY SAMPLES

	May 1st	May 8th	May 15th	May 22nd	May 29th	Jun 5th	Jun 12th	Jun 19th	Jun 26th	Jul 3rd	Jul 10th	Jul 17th	Jul 24th	Jul 31st	Aug 7th	
Borough Road	2.3	7.6	2.5	1.5	2.4	2.0	1.7	1.1	1.2	1.3	1.3	3.4	3.0	2.1	1.3	1
A 3	2.1	3.6	2.6	2.2	2.6	1.8	1.2	1.0	1.0	1.0	1.1	3.6	2.7	1.9	1.1	1
Stanbridge	3.0	3.8	3.4	3.8	3.7	3.2	3.2	4.7	4.75	4.8	6.3	3.5	4.9	5.1	5.7	5
Torberry	dry	2.0	1.4	0.7	0.5	0.3	0.3	0.2	0.3	0.4	0.3	1.0	0.2	0.2	0.1	0
Goose Green	1.9	3.4	2.0	1.9	2.0	1.8	1.8	1.8	1.75	1.7	1.9	2.8	1.9	1.7	1.8	1
Parks Bridge	1.1	2.8	1.1	1.2	1.0	0.9	0.8	0.8	0.75	0.7	0.6	1.0	0.5	0.5	0.4	0
Mizzards	0.9	2.6	1.0	1.6	1.0	0.9	0.8	1.1	1.1	1.1	1.1	1.3	1.1	1.0	0.9	0
South Harting	1.8	2.4	2.1	1.9	2.0	1.8	1.7	1.3	1.2	1.1	1.0	1.7	1.2	1.2	1.1	1
Weeks Common	7.9	5.3	6.6	6.8	8.8	6.7	5.1	8.1	8.25	8.4	9.2	5.3	7.0	8.4	8.9	9
New Barn	4.3	3.6	4.8	5.0	7.7	4.8	3.7	7.6	7.4	7.2	7.7	4.5	6.5	7.4	7.5	8
South Downs	5.3	3.6	5.5	5.3	6.8	5.2	4.6	7.4	7.15	6.9	7.2	4.9	6.3	7.1	6.9	7
Dumpford Park	4.4	4.5	5.2	5.2	4.0	4.8	4.5	5.0	4.7	4.4	5.2	6.4	5.0	5.1	4.7	4
Goldrings	9.2	6.4	8.5	15.0	9.8	8.2	9.4	9.2	8.3	7.4	7.4	8.8	7.3	7.3	8.5	9

MAIN RIVER WEEKLY SAMPLES

	Aug 21st	Aug 28th	Sept 4th	Sept 11th	Sept 18th	Sept 25th
Greatham Stream	0.9	0.9	0.9	0.9	0.9	0.9
Hawkley Stream	4.8	4.8	4.8	4.8	4.8	4.8
Liss	2.2	2.2	2.2	2.2	2.2	2.2
Prince's Bridge	3.4	3.4	3.4	3.4	3.4	3.4
Sheet	2.6	2.6	2.6	2.6	2.6	2.6
Durford	4.9	4.9	4.9	4.9	4.9	4.9
Habin	3.1	3.1	3.1	3.1	3.1	3.1
Terwick	3.0	3.0	3.0	3.0	3.0	3.0
Chithurst	3.7	3.7	3.7	3.7	3.7	3.7
Hammer	1.5	1.5	1.5	1.5	1.5	1.5
Iping	3.1	3.1	3.1	3.1	3.1	3.1
Barefoots	1.9	1.9	1.9	1.9	1.9	1.9
A 325	1.1	1.1	1.1	1.1	1.1	1.1
Coldhays	2.9	2.9	2.9	2.9	2.9	2.9
Flexcombe	3.3	3.3	3.3	3.3	3.3	3.3
Prince's Bridge	1.9	1.9	1.9	1.9	1.9	1.9
Roke	1.6	1.6	1.6	1.6	1.6	1.6
Harrow	1.8	1.8	1.8	1.8	1.8	1.8
Mill Lane	1.9	1.9	1.9	1.9	1.9	1.9
Berelands	11.2	11.2	11.2	11.2	11.2	11.2
Frenchman's Lane	1.5	1.5	1.5	1.5	1.5	1.5
B 2146	1.7	1.7	1.7	1.7	1.7	1.7
Stroud	1.0	1.0	1.0	1.0	1.0	1.0

MAIN RIVER WEEKLY SAMPLES

	Aug 21st	Aug 28th	Sept 4th	Sept 11th	Sept 18th	Sept 25th
Borough Road	1.2	1.2	1.2	1.2	1.2	1.2
A 3	1.2	1.2	1.2	1.2	1.2	1.2
Stanbridge	5.9	5.9	5.9	5.9	5.9	5.9
Torberry	0.1	0.1	0.1	0.1	0.1	0.1
Goose Green	1.6	1.6	1.6	1.6	1.6	1.6
Parks Bridge	0.5	0.5	0.5	0.5	0.5	0.5
Mizzards	1.0	1.0	1.0	1.0	1.0	1.0
South Harting	1.3	1.3	1.3	1.3	1.3	1.3
Weeks Common	9.2	9.2	9.2	9.2	9.2	9.2
New Barn	8.5	8.5	8.5	8.5	8.5	8.5
South Downs	6.7	6.7	6.7	6.7	6.7	6.7
Dunford Park	4.5	4.5	4.5	4.5	4.5	4.5
Goldrings	9.1	9.1	9.1	9.1	9.1	9.1

SEWAGE WORKS

WEEKLY SAMPLES

	1972 Oct 4th	Oct 11th	Oct 18th	Oct 25th	Nov 1st	Nov 8th	Nov 15th	Nov 22nd	Nov 29th	Dec 6th	Dec 13th	Dec 20th	Dec 27th	1973 Jan 3rd	Jan 10th
Petersfield Effluent	19.3	19.0	22.3	13.7	14.2	16.0	13.6	13.1	16.8	4.8	4.9	9.6	16.9	9.3	10.4
Liss Effluent	28.5	30.0	26.4	16.0	17.6	21.0	16.2	17.2	15.5			14.2	17.0	9.6	8.4
Durford		5.7	5.8	3.6	3.9	3.5	4.4	6.2	5.8	4.9	3.3	3.7	4.4	3.5	3.1
Stanbridge		5.4	9.4	6.3	4.0	4.8	8.8	8.1	7.6	4.6	3.6	4.1	4.2	3.2	3.5
Sheet		3.9	4.7	3.1	2.6	2.5	3.5	4.9	4.4	5.1	3.4	3.6		2.4	2.7
Prince's Bridge		4.5	4.4	2.3	3.0	2.9	4.0	4.5	5.0	4.3	3.1	3.4	3.8	2.8	3.1
Above Liss Effluent		2.9	3.1	2.0	1.9	1.7	3.2	4.1	4.6	4.3	3.1	2.1	3.0	2.3	2.4

	Jan 17th	Jan 24th	Jan 31st	Feb 7th	Feb 14th	Feb 21st	Feb 28th	Mar 7th	Mar 14th	Mar 21st	Mar 28th	Apr 4th	Apr 11th	Apr 18th	May 25th	May 2nd
Petersfield Effluent	9.4	10.8	15.6	10.4	9.0	11.4	12.0	10.2	11.3	9.8	11.0	11.1	13.2	13.4	14.9	14.
Liss Effluent	13.8	19.4	14.8	16.8	12.5	18.8	14.8	17.6	13.2	15.6	19.4	11.2	21.4	23.5	20.5	21.
Durford	4.8		4.8	3.6	3.8	5.2	4.3									
Stanbridge	5.1	4.6	4.3	4.5	3.7	4.4										
Sheet	3.9		2.9	3.2	3.0	5.4	3.2									
Prince's Bridge	3.9		3.6	3.7	3.4	4.5	3.6									
Above Liss Effluent	3.6	3.0	2.8	3.1	3.5	2.8										

SEWAGE WORKS WEEKLY SAMPLES

	May 9th	May 16th	May 23rd	May 30th	Jun 5th	Jun 12th	Jun 19th	Jun 26th	Jul 3rd	Jul 10th	Jul 17th	Jul 24th	Jul 31st	Aug 7th	Aug 14th
Petersfield Effluent	14.2	15.5	16.2	18.0	17.2	18.2	17.7	18.0	15.5	13.5	18.6	17.6	19.2	18.7	18.1
Liss Effluent	20.6	23.0	24.0	29.0	27.5	23.5	25.4	24.6	21.2	24.5	27.3	28.4	30.0	27.4	29.1

	Aug 21st	Aug 28th	Sept 4th	Sept 11th	Sept 18th	Sept 25th
Petersfield Effluent	17.9	19.5	18.6	18.6	18.6	18.6
Liss Effluent	28.9	27.5	28.6	28.6	28.6	28.6

FARMS

WEEKLY SAMPLES

	1972 Oct 2nd	Oct 9th	Oct 16th	Oct 23rd	Oct 30th	Nov 6th	Nov 13th	Nov 20th	Nov 27th	Dec 4th	Dec 11th	Dec 18th	Dec 25th	1973 Jan 1st	Jan 8th
Redlands	3.6	2.7	2.6	2.3	2.5	3.9	2.3	1.4	1.9	7.0	1.2	2.7	1.5	dry	1.5
North Didling															
Coombe Pond	0.4	0.37	0.31	0.3	0.3	0.78	3.4	5.6	0.86	4.7	2.5	2.1	1.2	1.8	0.77
Milland	1.1	0.62	0.72	0.4	0.45	0.85	5.1	6.4	2.5	7.2	5.5	5.1	3.3	3.0	1.9
Flex Cottage	2.0	2.0	0.77	0.55	3.4	0.65	41.0	34.0	11.8	16.5	11.0	7.6	7.0	6.9	5.6
Flex Farm	1.4	1.0	1.2	0.42	2.8	0.6	35.0	30.0	12.2	9.8	13.1	9.0	7.8	9.2	6.1
Andlers Ash			1.9	2.4	2.0	1.5	1.5	1.8	1.2	0.55	13.4	16.0	3.4	0.55	0.6
Barefoots			dry	0.66	0.9	1.1	1.3	2.5	2.0	0.6	24.0	23.0	1.7	25.5	4.2
Burgates	11.2	2.1	9.0	6.8	0.7	6.5	7.7	0.85	13.0	3.2	1.9	7.8	10.0	8.2	6.6
Durleigh Marsh	11.8	7.4	9.4	7.2	5.9	6.7		7.3		0.74	8.2	0.58	7.9	6.8	

FARMS	WEEKLY SAMPLES														
	Jan 15th	Jan 22nd	Jan 29th	Feb 5th	Feb 12th	Feb 19th	Feb 26th	Mar 5th	Mar 12th	Mar 19th	Mar 26th	Apr 2nd	Apr 9th	Apr 16th	Apr 23rd
Redlands	14.6	3.4	1.2	1.3	1.1	2.9	1.7	1.7	1.4	1.1	1.1	0.8	2.0	3.3	1.5
North Didling				0.4	0.45	5.5	0.6	0.9	0.8	0.6	0.4	5.8	0.6		0.9
Coombe Pond	3.4	2.8	2.7	0.9	1.0	2.0	1.4	0.8	0.4	0.3	0.2	3.8	0.9	0.6	0.2
Milland	4.0	5.2	4.0	2.5	2.1	3.8	2.6	2.1	1.7	1.2	1.2	6.8	2.3	1.1	1.5
Flex Cottage	12.2	9.6	6.8	6.4	6.7	8.9	6.6	5.5	5.0	4.0	3.4	14.3	5.4	3.6	5.5
Flex Farm	13.4	11.6	9.8	7.0	1.0	9.5	7.8	6.2	5.3	0.7	3.8	13.8	5.7	4.2	5.4
Andlers Ash		1.8	17.8	16.4	1.3	8.4	1.0	0.7	0.7	1.4	0.6		0.6	1.1	0.8
Barefoots	28.5	41.5	18.5	9.2	0.4	2.3	2.3	2.8	1.1	5.4	0.9	2.2	0.8	1.0	0.9
Burgate's	22.8	9.7	8.3	7.9	5.9	8.0	9.0	7.4	9.8	8.6	7.2	8.2	7.5	7.4	7.2
Durleigh Marsh	11.1	9.2	7.4	7.2	0.65	8.1		7.2	6.5		5.8	6.5	7.1	7.2	6.3

FARMS	Apr 30th	May 7th	May 14th	May 21st	May 28th	June 4th	Jun 11th	Jun 18th	Jun 25th	Jul 2nd	Jul 9th	Jul 16th	Jul 23rd	Jul 30th	Aug 6th
							WEEKLY SAMPLES								
Redlands	1.0	1.3	dry												
North Didling	9.2	3.4	1.1	1.5	dry										
Coombe Pond	0.6	2.0	0.5	0.4	0.2	0.3	0.4								
Milland	1.4	4.0	2.2	2.2	0.8	1.4	0.9								
Flex Cottage	3.8	8.8	5.3	3.7	3.7	1.5	3.1								
Flex Farm	2.7	9.6	5.0	5.9	4.1	2.8	3.5								
Andlers Ash	0.8	dry													
Barefoots	0.8	5.0	1.2	25.5	1.5	1.0	dry								
Durleigh Marsh	1.8	7.2	6.8	8.6	7.0	4.8	7.6								
Burgates	6.9	6.0		7.2	6.8	5.5	4.2								

SPRINGS WEEKLY SAMPLES

	1972 Oct 1st	Oct 8th	Oct 15th	Oct 22nd	Oct 29th	Nov 5th	Nov 12th	Nov 19th	Nov 26th	Dec 3rd	Dec 10th	Dec 17th	Dec 24th	Dec 31st	1973 Jan 7th
Durleigh Marsh SM	7.1	8.0	4.0	4.8		5.6	6.3	9.3	6.1	13.4	16.0	7.5	5.9	5.7	5.9
Durleigh Marsh LGE	4.1	4.6	7.0	5.1		3.1	3.9	4.8	4.0	6.6	7.4	6.3	4.6	4.3	4.7
Durford	7.2	8.2	7.7	6.8		3.6	2.0	2.7	4.0	4.8	5.9	6.6	5.9	6.2	6.3
Week's Common	5.5	6.2	6.2	6.0		4.3	4.4	3.3	4.5	4.2	3.7	4.0	3.8	4.4	4.4
South Harting	1.9	1.6	1.3	1.3				1.9	1.7	2.0	2.8	3.3	3.4	2.9	3.0
Mizzards	0.4	0.2	0.3	0.6		0.4	0.4	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.2
Harting Combe	0.3	0.2	0.2	0.5		0.2	0.3	0.2	0.3	0.3		0.2	0.2	0.3	0.2
Ashford	2.4	3.0	2.9	2.4		2.0	1.8	2.3	2.2	2.4	2.9	2.5	2.1	2.2	2.2
Higher Oakshott	2.7	2.9	2.9	2.6		1.9	2.1	2.7	2.5	4.2	4.1	3.6	2.0	2.9	2.7
Farewell's	6.8	7.9	7.4	7.2		5.5	5.6	6.5	5.8	7.6	6.1	6.1	5.1	5.3	5.7
Vann Farm	0.7	2.7	1.6	1.8		1.6	0.7	10.8	2.8	7.4	4.9	4.6	3.5	3.1	3.0
Empshott Green	3.5	3.6	2.5	3.0		2.6	1.8	3.7	3.3	5.1	12.1	12.0	8.8	7.4	6.7
Wyld Rose Cottage	3.4	4.2	3.1	3.2		2.8	2.9	3.3	2.8	3.3	2.9	2.8	2.2	2.9	2.9
Nursted Main Crundle										5.2	5.2	3.3	5.3	5.4	5.8
Nursted Small Spring										3.7	2.5	2.0	1.8	1.9	2.0
Ditchen											1.7	1.9	0.9	0.8	0.65
Buriton										4.4	3.8	3.2	3.3	3.6	3.4

SPRINGS WEEKLY SAMPLES

	Jan 14th	Jan 21st	Jan 28th	Feb 4th	Feb 11th	Feb 18th	Feb 25th	Mar 4th	Mar 11th	Mar 18th	Mar 25th	Apr 1st	Apr 8th	Apr 15th	Apr 22nd
Durleigh Marsh SM	10.4	7.3	6.2	5.5	6.2	6.0		6.2	5.5	7.0	5.7	6.3	5.5	6.3	4.4
Durleigh Marsh LGE	6.3	5.2	4.3	4.0	4.5	4.5	4.3	4.5	3.6	4.4	3.8	4.2	3.7	3.9	3.3
Durford	3.1	3.9	6.4	6.4	6.5	6.2	6.2	6.8	6.6	8.1	4.7	7.1	6.2	8.4	2.8
Week's Common	4.1	4.3	4.1	5.3	5.1	5.1	4.9	4.9	4.7	5.3	4.7	4.8	4.5	4.9	3.6
South Harting	2.9	2.9	3.3	3.4	3.6	3.4	3.3	3.4	3.2	3.5	3.0	2.4	2.6	2.8	1.8
Mizzards	0.74	3.7	1.4	0.25		1.7	2.3	1.9	0.6	0.4	0.3	0.35	0.4	0.4	0.3
Harting Combe	1.5	1.3	0.7	0.35	0.35	0.32	0.2	0.4	0.3	0.2	0.4	0.4	0.2	0.3	0.3
Ashford	2.4	2.8	2.5	3.0	2.6	2.6	2.5	3.0	2.6	2.7	2.3	2.3	2.4	2.4	2.2
Higher Oakshott	3.2	3.1	2.7	2.7	2.7	3.0	3.2	3.3	3.1	2.2	2.4	2.1	2.6	2.5	2.4
Farewell's	6.4	6.6	7.1	6.3	5.8	6.5	6.1	6.1	5.9	7.7	5.2	5.1	5.7	6.0	5.3
Vann Farm	4.0	4.4	3.6	4.3	3.0	3.8	3.0	2.9	3.3	2.9	2.9	2.8	2.6	2.6	0.7
Empshott Green	6.9	6.7	7.4	7.9	7.1	7.2	7.0	6.6	5.9	6.3	5.5	5.3	5.5	5.4	4.5
Wyld Rose Cottage	2.9	3.0	2.9	3.4	3.1	3.4	3.1	3.2	2.8	3.7	3.1	3.0	3.0	3.4	2.8
Nursted Main Crundle	6.0	6.2				6.1	6.5	4.9			6.8	6.2	6.0	6.7	6.3
Nursted Small Spring	3.5	2.5		2.4	2.0	2.5	2.4	2.4			0.7	2.2	2.6	2.7	2.5
Ditchen	1.0	1.0	0.88	0.75	0.75	0.7	0.65	0.9	0.8	0.6	0.4	0.5	0.5		
Buriton	4.0	4.3	4.2	5.8	4.4	4.8	4.9	5.0	4.4	5.6	4.9	3.5	4.2	4.9	3.1

	SPRINGS								WEEKLY SAMPLES							
	Apr 29	May 6th	May 13th	May 20th	May 27th	Jun 3rd	Jun 10th	Jun 17th	Jun 24th	Jul 1st	Jul 8th	Jul 15th	Jul 22nd	Jul 29th	Aug 5th	Aug 12th
Durleigh Marsh SM	5.3	6.3	7.0	5.9	5.7	5.4	5.2	4.8	4.8	5.3	5.1	6.1	5.1	4.8	4.7	4.7
Durleigh Marsh LGE	3.3	3.7	3.8	3.1	2.7	2.5	2.6	2.4	2.4	2.0	2.1	2.3	2.2	2.1	2.0	2.1
Durford	1.7	3.8	7.8	5.5	7.2	7.5	7.7	7.0	7.0	7.2	7.4	4.6	6.8	6.3	6.0	6.7
Week's Common	5.3	4.8	4.7	4.8	4.7	4.3	4.6	3.6	3.6	4.4	4.5	3.8	4.1	4.4	4.6	3.6
South Harting	2.3	2.4	2.7	2.5	2.0	1.8	1.8	1.5	1.5	1.7	1.7	1.4	1.5	1.5	1.5	1.4
Mizzards	0.3	0.3	0.4	0.4	0.3	0.2	0.2	0.3	0.3	0.5	0.4	0.2	0.3	0.3	0.3	0.2
Harting Coombe	0.4	0.5	0.3	0.3	0.4	0.3	0.2	0.2	0.2	0.3	0.5	0.3	0.2	0.2	0.2	0.2
Ashford	2.6	2.5	2.5	2.5	2.5	2.4	2.3	2.3	2.3	2.3	2.5	2.1	2.5	2.3	2.1	2.3
Higher Oakshott	2.7	2.9	3.0	2.6	2.5	2.7	2.6	2.5	2.6	2.5	1.9	2.5	2.3	2.4	2.1	2.3
Farewell's	5.9	6.1	6.8	6.4	6.4	6.0	5.4	5.4	5.0	6.1	5.8	5.7	5.7	5.7	5.4	5.0
Vann Farm	2.9	4.5	3.5	3.2	2.4	2.5	2.2	1.9	1.9	2.1	2.0	5.2	2.4	2.0	2.1	1.9
Empshott Green	6.1	5.2	7.0	6.0	6.1	5.0	5.6	5.0	5.2	4.9	4.8	4.4	5.0	5.4	4.7	4.8
Wyld Rose Cottage	2.7	3.2	3.2	3.4	3.6	2.3	2.4	2.7	3.2	2.6	2.4	2.6	2.3	2.4	2.3	2.3
Nursted Main Crundle	5.9	7.8	7.8	0.6												
Nursted Small Spring	2.6	2.8	3.3	3.0	3.0	2.1	2.1	1.9	1.0							
Ditchem		1.0	0.4	10.5	0.4											
Buriton	3.8	4.6	5.5	4.7	4.5	4.2	4.0	3.3	4.4	3.7	3.5	2.9	3.7	3.3	3.5	2.3

SPRINGS

WEEKLY SAMPLES

	Aug 19th	Aug 26th	Sept 2nd	Sept 9th	Sept 16th	Sept 23rd	Sept 30th	geology	total period of flow, out of 46.
Durleigh Marsh SM	4.7	4.7	4.7	4.7	4.7	4.7	4.7	L	46
Durleigh Marsh LGE	2.1	2.1	2.1	2.1	2.1	2.1	2.1	L	46
Durford	6.7	6.7	6.7	6.7	6.7	6.7	6.7	L	46
Weeks Common	3.6	3.6	3.6	3.6	3.6	3.6	3.6	U	46
South Harting	1.4	1.4	1.4	1.4	1.4	1.4	1.4	C	46
Mizzards	0.2	0.2	0.2	0.2	0.2	0.2	0.2	L	46
Harting Coombe	0.2	0.2	0.2	0.2	0.2	0.2	0.2	L	46
Ashford	2.3	2.3	2.3	2.3	2.3	2.3	2.3	C	46
Higher Oakshott	2.3	2.3	2.3	2.3	2.3	2.3	2.3	C	46
Farewells	5.0	5.0	5.0	5.0	5.0	5.0	5.0	U	46
Vann Farm	1.9	1.9	1.9	1.9	1.9	1.9	1.9	C	46
Empshott	4.8	4.8	4.8	4.8	4.8	4.8	4.8	C	46
Wyld Rose Cottage	2.3	2.3	2.3	2.3	2.3	2.3	2.3	L	46
Nursted Main Crundle								U	20
Nursted Small Spring								U	27
Ditchem								C	23
Buriton	3.2	3.2	3.2	3.2	3.2	3.2	3.2	C	36

geology:- L-Lower Greensand
U-Upper Greensand
C-Chalk

	FIELD DRAINS								WEEKLY SAMPLES						
	1972 Nov 18th	Nov 25th	Dec 2nd	Dec 9th	Dec 16th	Dec 23rd	Dec 30th	1973 Jan 6th	Jan 13th	Jan 20th	Jan 27th	Feb 3rd	Feb 10th	Feb 17th	Feb 24th
Goldrings Gate	17.0	21.0	25.9	10.7	14.4	13.5	13.7	14.7	2.8	13.4	15.2	15.0	13.4	13.8	12.0
Elsted East	16.8	16.4	19.2	11.7	11.7	9.6	7.4	6.3	5.7	10.3	9.7	11.2	10.9	13.0	11.8
Redlands	43.0		33.4	13.0	10.4				21.0	12.6					
Elsted	37.2		31.0	22.5	16.8	9.1			17.0	18.8					
East Harting	35.5		29.6	11.6	9.3	5.8	5.9	5.7	12.0	9.2	8.3	7.3	6.7	7.5	6.1
South Harting			9.4	7.3	7.1	5.5	5.5	5.3	7.0	6.1	4.2				
Nyewood			4.0	1.9	1.9			1.4	2.9	1.6	1.4	1.7	1.6	1.8	1.6
Durford Bridge			7.6	5.6		5.1	4.7	4.5	5.9				6.2	5.5	4.8
Durford Tile			8.3	5.8	5.8	3.7			6.5						
Ryefields			7.5	4.7	1.7	0.94		1.5	6.1			1.3	1.0	0.8	0.7
West Harting		6.1	9.0	8.5	8.2	4.8	4.0	3.0	6.8	4.9	3.6	3.7	3.4	5.5	4.1
Nursted			12.7	6.9	3.6				7.0					4.4	
Weston Field Drain			8.7	5.4	4.2	2.5			6.1				1.3	6.0	3.5
Stroud Bridge from N.		15.8	23.4	10.2	9.1	8.4	8.1	7.9	10.6	9.2	9.3	8.9	8.9	10.4	9.4
Stroud Bridge from S.		7.2	10.1	6.2	5.9	5.0	4.8	4.8	6.6	6.7	6.8	6.8	5.7	5.8	6.3
Roke			11.0	8.2	7.4	5.4	5.2	5.0	11.0	8.6	7.7	6.5	6.5	6.8	5.9
Barefoots			4.0	2.5	1.4	1.2	1.3	1.5	2.8	1.3	1.2	1.1	0.04	1.6	1.4
Burgates		10.4	13.4	12.4	8.5	7.7	7.5	8.3	11.2	8.5	8.7	9.9	9.3	9.0	9.6
A 325 N		9.0	15.6	15.0	14.0	9.5	7.5	6.6	13.8	13.0	9.4	9.4	11.5	11.5	7.4
A 324 S		1.9	4.5	6.0	2.4	0.84	0.9	0.9	1.2	2.6	1.5	0.9	1.1	3.0	1.7
Flex Cott Tile		18.7	32.2	30.0	27.8	25.0	24.3	23.5	27.3	26.5	27.2	29.6	27.7	29.0	27.8
Flex Cott Field Drain	19.0	15.0	18.3	7.0	8.8	6.6	6.1	4.7	9.6	8.6	7.2	6.2	6.5	7.4	5.1
Flex Farm Tile			1.5	1.0	0.7	0.8	0.3	0.3	0.4	0.3	0.4	0.3	0.55	0.4	0.35
Prince's Bridge Tile			2.5	0.7	1.2	1.6	0.9	1.2	0.65		1.0	1.1	0.65	0.74	0.95
Common Wood F/D	1.9		2.3	0.6	0.76	0.8	0.8	0.51	1.2	0.7	0.7	0.6	0.75	0.55	0.65
Common Wood	1.4		2.1	0.7	0.42	0.4	0.4	0.42	0.97		0.4	0.45	0.5	0.5	0.25

	Mar 3rd	Mar 10th	Mar 17th	Mar 24th	Mar 31st	Apr 7th	Apr 14th	Apr 21st	Apr 28th	May 5th	May 12th	May 19th	May 26th	Jun 2nd	Jun 9th
		FIELD DRAINS						WEEKLY SAMPLES							
Goldrings gate	11.2	8.8	9.4	4.8	3.2	6.2	3.5	2.4	1.6	1.7	1.1	0.8			
East Elsted	6.2					10.9				8.0					
Redlands										7.0					
Elsted								8.0		30.5					
East Harting	5.8	5.2	5.8	5.1	2.8	4.9	4.8			2.8	4.4				
South Harting															
Nyewood	1.0	1.3		3.1	1.5	0.6	0.9	1.3		1.7	0.5	1.3	0.6	0.7	
Durford Bridge															
Durford Tile															
Ryefields	0.7	0.8		1.7	1.0	0.4		3.8	0.4	2.7					
West Harting	3.8	3.5	4.2	4.0	3.8	5.5	3.3	4.3	4.2	6.6	5.2	3.5	2.7	1.9	
Nursted										5.7					
Weston Field Drain	1.7					4.4	2.3	1.7		6.5	2.6	0.5			
Stroud Bridge from N	7.6	6.5	4.7	6.3	2.2	5.7	2.3	5.4	1.9	6.5	3.6	0.9	1.9	1.3	
Stroud Bridge from S	5.1	4.0	4.7	3.0	2.3	4.1	3.6	3.3	3.2	3.7	4.7	3.8	3.9	3.4	3.4
Roke	5.5	4.8	4.8	4.4	3.0	5.0	4.2	10.8	4.6	12.0	4.3	0.8	2.8	1.4	
Barefoots	2.3	0.9	1.5	0.3	0.7	0.7	0.6	0.6	0.6	1.1	0.6	0.2	0.3	0.5	
Burgates	9.3	8.8	10.4	8.5	8.2	9.0	9.8	9.0	9.4	9.8	9.8	8.3	8.7	7.4	8.9
A 325 N	6.1	3.5		0.6	6.3	1.1		0.6		1.9					
A 325 S	1.5	0.8	1.5	1.5	1.4	1.0	2.0	1.6	1.3	1.3	1.4	1.2	1.4	1.6	
Flex Cott Tile	28.0	26.0	26.5	26.7	9.9	19.2	18.5	18.5	15.6	9.6	15.0	13.8	13.5		
Flex Cott Field Drain	3.7	4.0	5.2	3.0	6.2	3.9	2.4	2.8	1.0	7.1	2.3	1.6	0.5		
Flex Farm Tile	0.6	0.3	0.3	0.2	0.7	0.4	0.8	0.2	0.3	0.2	0.2	0.2	0.3	0.1	
Prince's Bridge Tile						0.6	0.8	0.5	0.4	0.6	0.4	0.5	0.1		
Common Wood F/D	0.45	0.7	0.7		0.3	0.6	0.7	0.6	0.2	0.7	0.6	0.3	0.4	0.5	
Common Wood	0.35	0.3			0.2	0.5	0.3	0.3	0.3	0.7	0.3	0.3	0.1	0.3	

	FIELD DRAINS						WEEKLY SAMPLES	
	Jun 16th	Jun 23rd	Jun 30th	Jul 7th	Jul 14th	Jul 21st	geology	period of flow
Goldring's Gate							G	27
East Elsted							U	18
Redlands							U	7
Elsted							U	9
East Harting							U	23
South Harting							U	9
Nyewood							L	23
Durford Bridge							L	9
Durford Tile							L	5
Ryefields							L	18
West Harting							U	28
Nursted							U	26
Weston Field Drain							U	15
Stroud Bridge North							G	28
Stroud Bridge South	3.6	3.4	3.5				G	32
Roke							U	27
Barefoots							U	27
Burgates	9.0	9.0	9.0	9.0	9.2	8.4	G	35
A 325 N							L	21
A 325 S							L	28
Flex Cott Tile							G	27
Flex Cott Field Drain							G	23
Flex Farm Tile							G	26
Prince's Bridge							L	20
Common Wood F/D							W	27
Common Wood							W	25

Geology:-
U-Upper Green-sand
L-Lower Green-sand
W-Weald Clay

APPENDIX 3

SAMPLING VARIABILITY

APPENDIX 3.

REPLICATE SAMPLES

Table 1

2nd Sept. 1972

Station	Sample									
1 Iping	5.6	5.6	5.7	5.7	5.6	5.6	5.6	5.6	5.6	5.7
2 Hammer										
3 Chithurst										
4 Terwick										
5 Habin	5.4	5.5	5.5	5.6	5.5	5.5	5.4	5.5	5.5	5.5
6 Durford	7.4	7.3	7.3	7.4	7.4	7.4	7.4	7.3	7.4	7.4
7 Sheet										
8 Prince's Br.	5.4	5.3	5.4	5.4	5.5	5.3	5.5	5.5	5.3	5.4
9 Liss	3.2	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
10 Geatham	1.9	1.9	1.9	1.8	1.9	1.9	1.8	1.9	1.9	1.9
11 Hawkley	4.5	4.5	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
12 Goldrings	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
13 Dumpford Pk	9.6	9.7	9.6	9.6	9.6	9.7	9.7	9.6	9.6	9.7
14 South Downs	10.6	10.6	10.6	10.6	10.8	10.6	10.8	10.6	10.6	10.8
15 New Barn	8.4	8.3	8.3	8.4	8.4	8.4	8.4	8.4	8.4	8.4
16 Weeks Comm.	6.8	6.8	6.9	6.9	6.8	6.8	6.8	6.7	6.8	6.8
17 South Harting	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
18 Mizzards	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
19 Parks Br.										
20 Goose Green										
21 Torberry										
22 Stanbridge										
23 A3										
24 Borough Road										
25 Stroud										
26 B2146	1.1	1.2	1.2	1.2	1.2	1.1	1.1	1.2	1.2	1.2
27 Frenchmans La.	3.1	3.1	3.2	3.1	3.1	3.2	3.1	3.1	3.3	3.2
28 Berelands										
29 Mill Lane	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
30 Harrow										
31 Roke										
32 Prince's Br.	3.0	2.9	2.8	2.9	2.9	2.9	2.9	2.9	2.9	2.9
33 Flexcombe										
34 Coldhays										
35 A325										
36 Barefoots										

Table 2

5th Sept 1972.

Iping:

left	5.0	5.0	5.0	5.1	5.0	5.0	5.0	5.0	5.0	5.0
centre	5.1	5.1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
right	5.1	5.0	5.1	5.0	5.0	5.0	5.0	5.0	5.0	5.1

REPLICATE SAMPLES FROM SPRINGS AND FIELD DRAINS

4th Sept. 1972

Station										
Durleighmarsh spring 1	4.7	4.7	4.6	4.6	4.5	4.7	4.6	4.6	4.6	4.5
Durford spring	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.5	9.5	9.4
Vann Fm. sp.	3.5	3.6	3.5	3.6	3.6	3.5	3.6	3.5	3.8	3.6
Mizzards sp.	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Weeks Comm. sp.	6.8	6.7	6.7	6.9	6.8	6.8	6.8	7.0	6.9	6.8
South Harting sp.	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Buriton sp.	4.4	4.5	4.5	4.4	4.5	4.5	4.6	4.5	4.5	4.5
Empshot Green sp.	5.6	5.6	5.6	5.5	5.6	5.6	5.5	5.6	5.6	5.6
Farewells Fm. sp.	9.6	9.6	9.6	9.6	9.6	9.69	9.6	9.6	9.7	9.7
Ashford sp.	5.5	5.5	5.6	5.6	5.6	5.7	5.7	5.6	5.7	5.6
Harting Coombe sp.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Durlieghmarsh sp. 2	4.9	5.0	5.0	5.0	5.1	5.2	5.2	5.1	5.1	5.1

27th Jan. 1972

Stroud Br. Tile	7.4	7.5	7.4	7.0	6.8	7.5	8.0	7.3	7.8	8.2
Weston Tile	3.9	4.4	4.4	4.5	4.4	4.4	4.5	4.5	4.4	4.3
Nursted Tile	5.7	5.7	5.7	6.00	5.4	5.9	5.6	6.2	5.9	5.8
Stroud Br. Tile	6.6	6.5	6.4	6.0	6.7	6.3	6.2	6.3	6.3	6.0
Celias Wood	6.2	6.6	6.0	5.8	6.4	5.8	5.8	5.6	5.9	5.7
Durford Tile	5.6	5.0	6.1	5.5	5.8	6.0	5.8	6.2	5.9	5.3

SHORT TERM VARIATIONS IN THE NO3-N CONCENTRATIONS IN SPRINGS AND FIELD DRAINS

A. Over twenty four hours; Date 7 November 1972

Time	Ashford	Wyld Rose Cottage	Farewells	A325N	Flexcombe Cott.
01.00	2.0	2.6	5.5	9.5	16.8
04.00	2.0	2.5	5.1	9.5	16.8
07.00	2.1	2.3	4.9	9.6	16.7
10.00	2.3	2.4	4.9	9.8	17.0
13.00	2.0	2.6	5.6	9.9	16.8
16.00	2.1	2.3	4.8	9.6	16.7
19.00	2.3	2.4	5.4	9.8	16.8
22.00	2.1	2.5	4.8	9.8	16.9
01.00	2.3	2.5	5.0	9.8	17.0

B. Over one hour; Date; 7 September 1972

Time	Durleighmarsh A	Mizzards	Weeks Common
09.30	5.3	0.23	6.3
09.40	5.4	0.23	5.7
09.50	5.4	0.24	5.6
10.00	5.4	0.24	5.6
10.10	5.4	0.24	4.9
10.20	5.4	0.24	5.7
10.30	5.4	0.24	5.6

SHORT TERM VARIATIONS IN THE NO3-N CONCENTRATIONS AT SEWAGE WORKS

A. Over twenty four hours; Date: 6 September 1972

Time	Petersfield	Liss
00.00	*	26.5
03.00	*	26.8
06.00	18.6	26.4
09.00	17.9	27.3
12.00	18.8	29.0
15.00	18.4	26.7
18 00	18.9	26.8
21.00	*	26.8

* no access to effluent

B. Over one hour; Date: 6 September 1972

Time	Petersfield	Liss	Time
12.00	17.8	27.3	09.00
12.10	18.9	27.5	09.10
12.20	18.7	27.0	09.20
12.30	19.0	21.0	09.30
12.40	19.0	26.6	09.40
12.50	19.0	27.1	09.50

APPENDIX 4

SITE DESCRIPTION

Appendix 4

FIELD DRAINS - Site Description for locations see Fig.

Name	Geology	Land Use 72/3	Type
1. Goldrings	Gault	Arable - Cereals	Ditch
2. Elsted A	U.G.S.	Arable - Cereals	Tile
3. Redlands	U.G.S.	Arable - Cereals	Ditch
4. Elsted B	U.G.S.	Arable - Cereals	Ditch
5. East Harting	U.G.S.	Arable - Cereals	Ditch
6. South Harting	U.G.S.	Arable - Cereals	Ditch
7. Nyewood	L.G.S.	Non Arable-Pasture	Ditch
8. Durford Bridge	L.G.S.	Arable - Potatoes	Tile
9. Durford	L.G.S.	Non Arable-Cereals	Tile
10. Ryefield	L.G.S.	Non Arable - Pasture	Ditch
11. West Harting	U.G.S.	Non Arable - Pasture	Tile
12. Nursted	U.G.S.	Arable - Cereals	Tile*
13. Weston A	U.G.S.	Non Arable - Pasture	Tile
14. Weston B	U.G.S.	Non Arable - Pasture	Ditch
15. Stroudbridge A	Gault	Non Arable - Pasture	Ditch
16. Stroudbridge B	Gault	Non Arable - Pasture	Ditch
17. Roke	U.G.S.	Arable - Cereals	Ditch
18. Barefoots	U.G.S.	Non Arable - Pasture	Ditch
19. Burgates	Gault	Non Arable - Pasture	Ditch
20. A 325 N	L.G.S.	Arable - Cereals	Tile
21. A 325 S	L.G.S.	Non Arable - Rough Pasture	Tile
22 Flexcombe Cottages A	Gault	Arable - Cereals	Tile
23. Flexcombe Cottages B	Gault	Non Arable - Pasture	Ditch
24. Flexcombe Farm	Gault	Non Arable - Pasture	Tile
25. Prince's Bridge	L.G.S.	Non Arable - Pasture	Tile
26. Common Wood A	L.G.S.	Non Arable - Woodland	Ditch
27. Common Wood B	L.G.S.	Non Arable - Woodland	Tile

*Not included in analysis because of contamination.

APPENDIX 5

CHEMICAL ANALYSIS

The main interest was in inorganic nitrogen. The predominant form is the Nitrate species. Ammoniacal Nitrogen exists in large amounts in effluents from sewage works and farms. It is unlikely that Nitrites exist in measurable amounts. Oxidising conditions predominate in the river and its tributaries and it is also ulikely that high concentrations of Ammoniacal Nitrogen will persist there. This was found to be the case in preliminary studies during 1971 - 2 (see Table Ai).

Ammoniacal Nitrogen was measured using a colorimetric test with Nessler's Reagent in strongly alkaline conditions. There are several factors which could interfere with this method and the data referring to sewage effluents could be very inaccurate. Those referring to river samples, where very little Ammoniacal Nitrogen exists, are probably reliable.

Nitrate was measured using a Corning - EEL Nitrate Electrode. In pilot studies before 1972 Nitrate was measured by a colorimetric technique using Brucine (Thomas and Chamberlain 1968).

Samples were obtained using a metal bucket andc care was taken not to include any living or dead animals and plants, organic matter and sediment. They were transferred to a laboratory in polythene bottles without any additions. Bottles were pre-washed with a portion of the sample. They were analysed within a few hours. No inhibitors nor special proceedures followed to prevent deterioration during this time. On a few occasions when samples were kept overnight for analysis they were stored

TABLE Ai

CONCENTRATIONS OF NO3-N AND NH4-N IN THE RIVER ROTHER

	ppm. NO3-N	ppm. NH4-N
HAWKLEY	3.6	n.m.
GREATHAM	1.4	n.m.
LISS	3.4	n.m.
PRINCE'S BRIDGE	4.6	0.2
SHEET	4.2	0.1
DURFORD	4.5	0.1
HABIN	4.1	n.m.
TERWICK	4.3	0.2
CHITHURST	5.0	n.m.
IPING	5.1	n.m.

n.m. not measurable

in the dark.

Experiments were conducted to test for deterioration. One was conducted during December 1972 and a second during May 1973. Five splits of the same sample were taken and analysed for Nitrate Nitrogen after thirty minutes, four hours, twelve hours, twenty four and seventy two hours (Table Aii).The samples taken in December showed slight deterioration only beyond twenty four hours. Those in May had shown signs of deterioration after twelve hours and after seventy two hours it was serious. The difference is undoubtably due to the presence of aquatic organisms during the summer months.

Samples were not stored frozen for later analysis.

<u>AMMONIACAL NITROGEN</u>.

The test for ammoniacal Nitrogen was taken from the Lavibond manual "Colorimetric Chemical Analytical Methods" (Thomas and Chamberlain 1967) and is a standard method for river waters.

To 8 ml of sample were added 1 ml of 25% w/v NaOH solution and 1 ml of Nessler's Reagent. The resultant colour extinction was measured with an EEL portable colorimeter with a No 625 (Green) filter. Distilled water was used as a blank Standards were prepared using Ammoniacal Nitrate in the range 0. 1 to 20 mg/1 w/v of Ammoniacal Nitrogen. Above this concentration dilution was necessary..

TABLE Aii

CHANGES IN NO3-N CONCENTRATION OF REPLICATE SAMPLES OVER TIME

HOURS	DECEMBER	MAY
00.0	7.1	5.3
00.5	7.1	5.3
04.0	7.0	5.3
12.0	6.9	4.4
24.0	6.5	3.9
72.0	6.4	2.6

Calibrations were performed with new batches of Nessler's Reagent and on replacemant of the bulbs of the colorimeter.

The main interference in this test is likely to be from Creatin and related organic compounds. In the analysis of sewage effluents it is possible that these interferences were serious. No pre-treatments were performed and there remains the possibility of large errors in measurements on these samples. However, no serious descrepancies (an order of magnitude) from analyses published in the literature were observed. Furthermore independent analyses of the effluent samples provided very similar results from the test used in this study. (Table Aiii).

Reproducability of results was established under normal running conditions to a precision of :

0.1 mg/l in the 0 to 1 mg/l range.

0.2 mg/l in the 1 to 2 mg/l range.

0.5 mg/l in the 2 to 10 mg/l range.

1.0 mg/l in the 10 to 20 mg/l range.

NITRATE NITROGEN.

Nitrate Nitrogen was measured using a Corning - EEl Nitrate electrode in conjunction with a Corning - EEL expanded scale pH meter (Edwards, McDonald and Petch, 1975).

Concentrations were measured quickly and simply by immersing the electrode and a reference electrode into the sample. A small degree of shaking was required to ensure mixing and more rapid settling of the instrument. Calibration against a 10 mg/l w/v solution of Nitrate Nitrogen was performend at the beginning of each period of analysis and at intervals during it. A tendency for shift was found during the analysis of the first ten or twenty samples. This was always observed, corrected and the samples re-analysed.

The main important interfering ions are the Arsenate and Perchlorate species. These are extremely unlikely to occur in this river and their possible effects were ignored. The only ion likely to interfere was Chloride. This interferes to the extent of 1/250 th of its concentration. Levels of chloride in the Rother and its tributaries are of the order of 30 ppm (A. M. C. Edwards, personal communication). A selected set of samples analysed independently acc orded with this figure (Table Aiii) Thus a consistent error of the order of 0. 1 mg/l occured. This is hereafter ignored.

Reproducibility of results was established under normal runnung conditions to a precision of:

0.05 to 0.10 mg/l in the range 0.1 to 1.0 mg/l NO_3-N

0.10 to 0.20 mg/l in the range 1.0 to 10 mg/l NO_3-N

0.20 to 2.00 mg/l in the range 10 to 100 mg/l NO_3-N

The electrode did not perform with a linear response at concentrations below 0.3 mg/l NO_3-N.

The data used in this thesis are presented in Appendix 5.

TABLE Aiii

INDEPENDENT ANALYSES OF REPLICATE WATER SAMPLES

SAMPLE No.	ppm. NO3-N		ppm. Cl^-
	Method 1	Method 2	
1	17.0	17.0	50.4
2	27.7	28.0	31.9
3	19.0	20.0	44.0
4	1.4	1.4	29.8
5	0.7	0.6	24.5
6	4.2	4.4	28.4
7	4.1	4.5	25.5
8	2.8	3.6	20.6
9	2.4	3.0	21.3
10	1.7	1.7	25.9
11	5.8	11.8	234.0
12	3.6	4.2	23.1
13	5.7	5.5	28.4
14	7.0	2.9	356.3
15	3.2	4.0	27.3
16	1.3	2.0	18.0
17	2.8	3.9	29.8
18	2.8	2.7	22.7
19	4.0	4.6	22.0
20	12.3	14.3	30.1

continued.

TABLE Aiii continued

21	3.2	3.5	20.2
22	3.3	4.7	29.1
23	9.0	10.3	30.5
24	7.7	8.0	28.7

Method 1. Modified Griess- Ilovasy
performed by Fison's Levington Research Station

Method 2. Nitrate Electrode by the author

Chloride analysed by Mohr's method.

Variations within $\pm$ 0.2 ppm (or $\pm$ 0.2 mg/l) NO_3-N are not regarded as different because of the likely errors in measurement.

APPENDIX 6.

DATA USED IN ANALYSIS OF VARIANCE.

DATA USED IN ANALYSIS OF VARIANCE.

SPRINGS.

Upper Greensand

I	Dry	6.2	6.0	3.8	5.1	5.3
	Wet	3.7	6.1	6.1	3.3	3.7
II	Dry	2.4	4.9	5.3	5.2	6.1
	Wet	4.1	4.3	6.4	6.0	2.5
III	Dry	5.3	4.7	6.8	6.0	3.0
	Wet	4.8	5.1	4.8	5.9	6.1
IV	Dry	4.4	4.5	4.4	6.1	5.8
	Wet	3.8	5.2	4.5	4.5	4.5

Chalk

I	Dry	1.3	2.0	3.0	1.8	2.5
	Wet	1.8	2.5	3.6	4.6	3.2
II	Dry	3.3	3.0	3.4	3.5	2.2
	Wet	2.4	3.1	4.4	3.6	2.7
III	Dry	2.4	3.1	1.8	2.6	1.9
	Wet	2.3	2.3	2.7	2.9	4.5
IV	Dry	1.5	2.3	2.0	2.4	3.7
	Wet	1.4	2.5	2.2	4.4	2.9

Lower Greensand

I	Dry	4.6	6.8	5.9	0.2	4.2
	Wet	7.4	6.3	0.3	2.9	2.8
II	Dry	1.4	3.6	3.8	6.2	0.6
	Wet	4.5	6.5	1.5	6.3	5.2
III	Dry	4.4	2.8	2.6	7.0	0.2
	Wet	0.3	1.7	3.8	2.7	3.2
IV	Dry	5.1	2.1	2.2	7.2	2.3
	Wet	2.3	4.6	0.2	0.3	2.6

FIELD DRAINS

Upper Greensand

I	Arable	Dry	7.4	5.9	5.5	5.2	6.0
		Wet	43.0	10.4	31.0	7.4	16.8
	Non-arable	Dry	4.0	1.3	2.7	2.7	2.6
		Wet	8.5	8.7	5.4	4.0	1.4
II	Arable	Dry	6.3	6.2	6.7	4.2	6.5
		Wet	10.3	12.0	9.2	4.4	11.0
	Non-arable	Dry	3.7	3.4	3.8	2.3	0.9
		Wet	4.9	5.5	6.1	2.8	1.6
III	Arable	Dry	8.0	4.8	4.2	10.8	4.6
		Wet	8.0	7.0	30.5	12.0	1.1
	Non-arable	Dry	2.7	1.9	1.7	0.6	0.6
		Wet	5.5	4.4	6.5	0.7	1.1

Lower Greensand

I	Arable	Dry	4.7	7.5	6.1	6.1	6.1
		Wet	7.6	5.6	5.1	9.0	14.0
	Non-arable	Dry	0.9	0.9	0.9	0.9	0.9
		Wet	1.9	5.8	1.7	1.9	6.0
II	Arable	Dry	7.2	9.4	6.2	0.6	6.3
		Wet	5.9	5.5	13.8	13.0	11.5
	Non-arable	Dry	1.0	3.1	1.7	1.4	0.9
		Wet	6.5	2.9	1.6	3.0	1.8
III	Arable	Dry	0.6	0.6	0.6	0.6	0.6
		Wet	1.1	1.9	1.5	1.5	1.5
	Non-arable	Dry	1.3	1.2	0.8	0.5	0.1
		Wet	1.7	1.0	1.3	1.4	0.6

Gault

I	Arable	Dry	13.7	24.3	19.0	19.0	19.0
		Wet	10.7	14.4	13.5	18.7	27.8
	Non-arable	Dry	8.1	4.8	7.5	6.1	0.3
		Wet	23.4	5.0	13.4	8.5	7.0
II	Arable	Dry	3.2	23.5	27.8	28.0	9.9
		Wet	13.4	13.8	27.3	26.5	29.0
	Non-arable	Dry	9.9	5.1	6.3	5.1	6.2
		Wet	6.6	10.4	5.8	9.0	8.6

FIELD DRAINS - continued....

Gault continued....

III	Arable	Dry	3.5	1.6	0.8	18.5	15.6
		Wet	6.2	1.1	19.2	9.6	15.0
	Non-arable	Dry	3.6	9.0	2.4	2.8	0.3
		Wet	5.7	2.6	3.7	7.1	0.2

APPENDIX 7

COMPUTER PROGRAM

```
JOB FILEIN.:EG08
INPUT HYDRIT
ZFORTRAN TIME270
      PROGRAM(ASDA)
      INPUT1=CR0
      OUTPUT2=LP0
      TRACE2
      END
      MASTER MAIN
C         PROGRAM FOR COMPUTING WEEKLY NITRATE  NITROGEN VALUES AT THIRTY
C          SIX STATIONS IN THE ROTHER BASIN USING A REGRESSION ON.
C             LAND USE GEOLOGY SEASON AND DISCHARGE
C          AND ON A SIMPLE HYDROLOGICAL MODEL WHICH DISTRIBUTES THE FLOW AT THE
C           BASIN MOUTH TO THE THIRTY SIX SUB BASINS
```

```
C          THE  CHOICE OF INSERTING LAND USE CHANGES IN A SECOND YEAR IS GIVEN
C.... .        LIST OF VARIABLES
C          DX     LAND USE DATA FOR 36 SUB BASINS FOR YEAR 2
C          BX     REGRESSIONS COEFFICIENTS
C          SUM    COMPUTED MEANS AT 36 STATIONS; 8 SEASONAL MEANS AT EACH
C          DD     INDEPENDENT VARIABLES IN THE REGRESSION
C          D      MEASURED MEAN CONCENTRATION FROM SEWAGE WORKS
C          ND     TOTAL NUMBER OF WET WEEKS AND DRY WEEKS IN EACH OF 4 SEASONS
C          NW    -3ABELS OF WET WEEKS AND DRY WEEKS
C          NP     AREA OF EACH OF 5 ROCKS IN EACH OF 36 SUB BASINS
C          Q     TOTAL DISCHARGE PER UNIT AREA OF EACH ROCK PER WEEK
C          R      WEEKLY DISCHARGES FROM SUB BASINS AND SEWAGE WORKS
C          RR     WEEKLY DISCHARGES AT STATIONS
C          C      CONCENTRATIONS FROM SEWAGE WORKS AND SUB BASINS
C          CC     COMPUTED CONCENTRATIONS AT STATIONS
C          QQ     WEEKLY QUICKFLOW FROM EACH ROCK
C          BB     WEEKLY BASEFLOW FROM EACH ROCK
C          NQ     TOTAL WEEKLY QUICKFLOW
C          NB   . TOTAL WEEKLY BASEFLOW
C          DQ     TOTAL QUICKFLOW PER UNIT AREA OF EACH ROCK FOR EACH UNIT OF NQ
C          DB     TOTAL BASEFLOW PER UNIT AREA OF EACH ROCH FOR EACH UNIT OF NB
      DIMENSION DD(24,288),D(41,8),SUM(288),BX(24),DX(36)
      DIMENSION AG(52),AB(52)
      DIMENSION ND(8),NW(13,8)
      DIMENSION NP(36,5),Q(52,5),RR(36,52)
      DIMENSION LP(12),LQ(12),LR(12),LS(12)
      DIMENSION LT(12),LU(12)
      DIMENSION R(41,52)
      DIMENSION C(41,52),CC(36,52)
      DIMENSION QQ(52,5),BB(52,5)
      DIMENSION NQ(52),NB(52),DQ(5),DB(5)
      READ(1,555)(DX(K),K=1,36)
  555 FORMAT(20F4.1)
  613 FORMAT(8I3)
      DO 606 J=1,8
      READ(1,614)(NW(K,J),K=1,13)
  614 FORMAT(13I3)
  606 CONTINUE
      DO 605 I=1,288
      READ(1,610)(DD(K,I),K=1,24)
  610 FORMAT(20F4.1/4F4.1)
  605 CONTINUE
      DO 607 J=1,8
      READ(1,611)(D(K,J),K=37,41)
  611 FORMAT(20F4.1)
  607 CONTINUE
      READ(1,613)(ND(J),J=1,8)
      READ(1,612)(BX(J),J=1,24)
  612 FORMAT(13F6.3/11F6.3)
      DO 9 I=37,41
      READ(1,8)(R(I,J),J=1,52)
    8 FORMAT(20F4.1/20F4.1/12F4.1)
    9 CONTINUE
      READ(1,5)(LP(N),N=1,12)
      READ(1,5)(LQ(N),N=1,12)
      READ(1,5)(LR(N),N=1,12)
```

```
      READ(1,5)(LS(N),N=1,12)
    5 FORMAT(12I3)
      READ(1,5)(LT(N),N=1,12)
      READ(1,5)(LU(N),N=1,12)
      DO 12 I=1,36
      READ(1,10)(NP(I,J),J=1,5)
   10 FORMAT(5I4)
   12 CONTINUE
      READ(1,360)(AO(J),J=1,52)
      READ(1,360)(AB(J),J=1,52)
  360 FORMAT(20F4.1)
      READ(1,501)(DO(N),N=1,5)
      READ(1,501)(DB(N),N=1,5)
  501 FORMAT(5F5.3)
C....       OPTIONAL SECTION WHICH INSERTS LAND USE DATA FOR YEAR  2
      DO 330 J=1,52
      NO(J)=AO(J)*7.0
      NB(J)=AB(J)*7.0
  330 CONTINUE
      DO 321 J=1,36
      XX=DX(J)
      DO 322 K=1,8
      L=J*8-8+K
      M=K+17
      DD(10,L)=XX
      IF(M.EQ.25) GO TO 324
      DD(M,L)=XX
  324 CONTINUE
  322 CONTINUE
  321 CONTINUE
C......      OPTIONAL SECTION WHICH CORRECTS SEWAGE DISCHARGES FOR YEAR 2
      DO 550 J=37,41
      DO 550 K=1,52
      R(J,K)=R(J,K)*0.6752
  550 CONTINUE
C......      COMPUTATION OF REGRESSION MODEL TO PRODUCE 8 MEAN VALUES OF
C            NITRATE NITROGEN CONCENTRATION FOR 36 SUB BASINS AND
C            ARRANGE THEM INTO 36X8 MATRIX
      DO 521 I=1,288
      SUM(I)=0.0
      DO 521 J=1,24
      XX=BX(J)*DD(J,I)
      SUM(I)=SUM(I)+XX
  521 CONTINUE
      DO 301 J=1,36
      DO 301 K=1,8
      M=J*8-8+K
      D(J,K)=SUM(M)
  301 CONTINUE
C......      COMPUTATION AND PRINTING OF 52 WEEKLY VALUES FOR 36 SUB BASINS
C            EQUAL TO APPROPRIATE MEAN VALUES
      DO 710 LL=1,41
      DO 710 KK=1,8
      JJ=ND(KK)
      M=KK
      DO 710 K=1,JJ
```

```
      MM=NW(K,KK)
      C(LL,MM)=D(LL,M)
  710 CONTINUE
C....       COMPUTATION OF WEEKLY AMOUNTS OF BASEFLOW AND QUICKFLOW FROM
C           EACH SUB BASIN AND WEEKLY BASEFLOW AND QUICKFLOW AT EACH STATION
      DO 520 N=1,52
      DO 520 J=1,5
      NN=N
      JJ=J
      QQ(NN,JJ)=NQ(NN)*DQ(JJ)
  520 CONTINUE
      DO 530 N=1,52
      DO 530 J=1,5
      NN=N
      JJ=J
      BB(NN,JJ)=NB(NN)*DB(JJ)
  530 CONTINUE
      DO 540 NN=1,52
      DO 540 JJ=1,5
      Q(NN,JJ)=QQ(NN,JJ)+BB(NN,JJ)
  540 CONTINUE
      DO 30 NN=1,36
      DO 30 JJ=1,52
      RR(NN,JJ)=0.0
   30 CONTINUE
      DO 50 NN=1,36
      DO 55 JJ=1,52
      DO 35 LL=1,5
      RR(NN,JJ)=RR(NN,JJ)+NP(NN,LL)*Q(JJ,LL)
   35 CONTINUE
   55 CONTINUE
   50 CONTINUE
      DO 20 N=1,12
      DO 20 K=1,52
      NN=LP(N)
      NM=LO(N)
      R(NN,K)=RR(NM,K)
   20 CONTINUE
      DO 40 N=1,12
      MM=LT(N)
      MN=LT(N)-1
      JJ=LU(N)
      DO 40 K=1,52
      R(MM,K)=R(MN,K)+RR(JJ,K)
   40 CONTINUE
      DO 22 K=1,52
      R(3,K)=R(1,K)+R(2,K)+RR(3,K)
      R(4,K)=R(3,K)+R(13,K)+R(37,K)+RR(6,K)
      R(5,K)=R(19,K)+R(16,K)+R(4,K)+RR(13,K)
      R(26,K)=R(25,K)+R(38,K)+RR(20,K)
      R(6,K)=R(26,K)+R(22,K)+R(5,K)+R(39,K)+RR(21,K)
      R(7,K)=R(6,K)+R(30,K)+RR(26,K)
      R(32,K)=R(31,K)+R(40,K)+RR(28,K)
      R(33,K)=R(32,K)+RR(29,K)
      R(34,K)=R(33,K)+RR(30,K)
      R(8,K)=R(7,K)+R(34,K)+R(41,K)+R(35,K)+RR(31,K)
```

```
      R(9,K)=R(8,K)+R(36,K)+RR(34,K)
      R(10,K)=R(9,K)+R(11,K)+RR(36,K)
   22 CONTINUE
C....      COMPUTATION OF WEEKLY CONCENTRATIONS AT STREAM HEAD STATIONS
      DO 23 N=1,12
      DO 23 K=1,52
      NN=LO(N)
      NM=LP(N)
      CC(NM,K)=C(NN,K)
   23 CONTINUE
C....      COMPUTATION OF WEEKLY CONCNENTRATIONS AT DOWSTREAM STATIONS
      DO 25 N=1,12
      DO 25 K=1,52
      NN=LS(N)
      NM=LR(N)
      JJ=NM-1
      CC(NM,K)=(R(JJ,K)*CC(JJ,K)+RR(NM,K)*C(NM,K))/R(NM,K)
   25 CONTINUE
      DO 32 K=1,52
      CC(3,K)=(R(2,K)*CC(2,K)+R(1,K)*CC(1,K)+RR(3,K)*C(3,K))/R(3,K)
      CC(4,K)=(R(3,K)*CC(3,K)+R(13,K)*CC(13,K)+R(37,K)*C(37,K)+RR(8,K)*C
     1(6,K))/R(4,K)
      CC(5,K)=(R(4,K)*CC(4,K)+R(16,K)*CC(16,K)+R(19,K)*CC(19,K)+RR(13,K)
     1*C(13,K))/R(5,K)
      CC(26,K)=(R(25,K)*CC(25,K)+R(38,K)*C(38,K)+RR(20,K)*C(20,K))/R(26,
     1K)
      CC(6,K)=(R(5,K)*CC(5,K)+R(22,K)*CC(22,K)+R(26,K)*CC(26,K)+R(39,K)*
     1C(39,K)+RR(21,K)*C(21,K))/R(6,K)
      CC(7,K)=(R(6,K)*CC(6,K)+R(30,K)*CC(30,K)+RR(26,K)*C(26,K))/R(7,K)
      CC(32,K)=(R(31,K)*CC(31,K)+R(40,K)*C(40,K)+RR(28,K)*C(28,K))/R(32,
     1K)
      CC(33,K)=(R(32,K)*CC(32,K)+RR(29,K)*C(29,K))/R(33,K)
      CC(34,K)=(R(33,K)*CC(33,K)+RR(30,K)*C(30,K))/R(34,K)
      CC(8,K)=(R(7,K)*CC(7,K)+R(32,K)*CC(32,K)+R(41,K)*C(41,K)+RR(31,K)*
     1C(31,K))/R(8,K)
      CC(9,K)=(R(8,K)*CC(8,K)+R(36,K)*CC(36,K)+RR(34,K)*C(34,K))/R(9,K)
      CC(10,K)=(R(9,K)*CC(9,K)+R(11,K)*CC(11,K)+RR(36,K)*C(36,K))/R(10,K
     1)
   32 CONTINUE
C....      COMPUTATION OF MEANS OF WEEKLY VALUES FOR EACH SEASON AND DISCHARGE
C          STATE FOR 36 STATIONS
      DO 195 N=1,36
      DO 190 K=1,8
      J=ND(K)
      SUM(K)=0.0
      DO 180 KK=1,J
      M=NW(KK,K)
      SUM(K)=SUM(K)+CC(N,M)
  180 CONTINUE
      SUM(K)=SUM(K)/J
  190 CONTINUE
      WRITE(2,196)N
      WRITE(2,197)(SUM(K),K=1,8)
  196 FORMAT(///, ' MEAN VALUES AT STATION ' ,I10)
  197 FORMAT(//, 10X,8F8.1)
  195 CONTINUE
```

```
STOP
END
FINISH
```

BIBLIOGRAPHY

Allisson,F.E.(1955): The enigma of soils nitrogen balance sheets; Adv. Agronomy, 7, 213-299

Allisson,F.E.(1966): The fate of Nitrogen applied to soils; Adv. in Agronomy, 8, 219-258

Angstrom,A., & Hogberg,L.(1952): On the content of Nitrogen in atmospheric precipitation; Tellus, 4, 31-42

Angstrom,A., & Hogberg,L.(1952a): On the content of Nitrogen in atmospheric precipitation in Sweden, II; Tellus, 4, 271-279

Amoroco,J., & Hart,W.E.(1964): A critique of current methods in hydrologic systems investigation; Trans.Am.Geophys Union, 45, 307-321

AWWA Committee Report(1966): Nutrient associated problems in water quality and treatment; J.Amer. Water Works Assoc., 58, 1337-1355

AWWA Committee Report(1967): Sources of Nitrogen and Phosphorus in water; J.Amer.Water Works Assoc., 59 344-366

AWWA Committee Report(1970): Chemistry of Nitrogen and Phosphorus in water; J.Amer.Water Works Assoc., 62, 127-140

Bormann,F.H. & Likens,G.E., Eaton,J.S.(1969): Biotic regulation of particulate and solution losses from a forest ecosystem; Bio.Sci., 19, 600-610

Brewin,D.J., Chang,M.S.T., Porter,K.S., & Warn,A.E.(1972): Trent mathematical model (b) development. IWE Birmingham Symp. on Adv. Techniques in River Management; 169-192

British Regional Geology(1965): The Wealden District (4th edition) H.M.S.O., London, pp. 165

Butcher,R.W.(1933): Studies on the ecology of rivers, I - On the distribution of macrophytic vegetation in the rivers of Britain; J.Ecol., 21, 58-91

Butcher,R.W.(1947): Studies on the ecology of rivers, VII - The algae of organically enriched waters; J.Ecol. 35, 186-191

Chu,S.P.(1943): The influence of the concentration of inorganic Nitrogen and Phosphate Phosphorus; J. Ecol., 31, 109-148

Comley,H.H.(1945): Cyanosis from Nitrates in well water; Amer. Medical J., 129, 112-116

Cooke,G.W.,& Williams,R.B.J.(1970): Losses of Nitrogen and Phosphorus from agricultural land. Water Tret. & Exam.19, 253-276.

Davis,J.A.& Slack,B.(1964): The Rivers Blackwater and Chelmer - hardness,sulphate,chloride,and nitrate content. Water Tret. and Exam.13,12-19.

Deutsch,M.(1963):Ground water contamination and legal controls in Michigan. US.Geol.Survey,Water Supply Paper,1691 79pp.

Diamond,W.E.,de B.(1937): Fluctuations in Nitrogen content of some Nigerian Soils,I.Empire.J.Exp.Agron.5,264-280.

Dillenberg,H.O.,& Dehnel,M.K.(1960) : Toxic water bloom in Saskatchewin,1959. Can.Med.Assoc,J.83,1151-1152.

Dixon,N.,& Hendricks,D.W.(1970):Simulation of spatial and temporal changes in water quality within a hydrological unit. Water Res.Bull.6,1547-1559.

Dowling,J.N.(1974):A note on the use of spectral analysis to detect leads and lags in annual cycles of water quality.Water Res.Res.10,343-344.

Dugdale,V.A.,& Dugdale,R.C.(1962):Nitrogen metabolism in lakes II, role of nitrogen fixation in Sanctuary Lake,Pa. Limnol. & Oceanog.7,170-194.

Durum,W.H.(1953):Relationship of mineral constituents in solution to stream flowSaline R.,Russel,Kansas.Trans.Amer. Geophys.Union,34,435-445.

Edwards,A.M.C.(1973a): The variation if dissolved constituents with discharge in some Norfolk rivers. J.Hydrol.,18,219-242.

Edwards,A.M.C.(1973b):Dissolved load and tentative solutes budgets of some Norfolk catchments. J.Hydol.18,201-217.

Edwards, A.M.C.,McDonald,A.T.,&PetchJ.R.(1975): The use of electrode instrumentation for water analysis.Brit.Geomorphological Research Group,Technical Bull.14,39pp.

Edwards,A.M.C., & Thornes,J.B.(1973):Annual cycle in river water quality.A time series approach.Wat.Res Res.9,1286-1259.

Erriksson,E.(1955):Air born salts and the chemical composition of river water. Tellus,7,118-124.

Faulkner,C.H.(1972):DO predicyion model for a long river. Water Resources Res. 8,1547-1549.

Feth,J.H.(1966):Nitrogen compounds in natural waters- a review. Water Resources Res. 2,41-58.

Findeneg,I.(1971):Productivity of some planktonic species of algae in their natural environment. Arch.Hyrdo.Biol., 69,273-291.

Fisher,D.W,,et al.(1968):Atmospheric contribution to water quality of streams in the Hubbard Brook experimental forest. Water Resources Res. ,4,1115-1126.

Fitzgerald,G.P.,& Rohlich,G.A.(1958):An evaluation of stabalisation pond literature.Sewage and Industrial Wastes,30, 1213-1230.

Flippen,E.O.(1945):Plant nutrient losses in silt and water in the Tenessee Valley. Soil Sci.,60,223-239.

Foster, S.S.B.,& Crease,R.I.(1974):Nitrate pollution of chalk ground water in E.Yorkshire - A hydrological appraisal . J.Inst.Water Eng.,28,178-194.

Fruh,G.E.(1967):The overal picture of eutrophication. Inst.Water Pollut.Cont.Fed.,39,1449-1463.

Gachter,R.(1968): Phosphorhansalt und plankische Primarproduktion im Vierwaldstersee(Horwer Bucht).Schweiz.Z.Hydrol., 30,1-66.(in German).

Galegar,W.C.(1969):Pollution effects in rural watersheds.Symp. on Watershed changes and stream flow. Water Res Symp.2. 150-154.

Gambell,A.W.,& Fisher,D.W.(1964):Occurrance of sulphate and nitrate in rainfall. J.Geophys.Res.69,4203-4210.

Gardner,W.R.(1965): Movement of Nitrogen in soils. In,Soil Nitrogen,US Soc. of Agron.,ed.Bartholomew,W.V.,& Clarke,F.E.,550-571.

George,W.O.,& Hastings,W.W.(1951): Nitrstes in groundwater of Texas. Trans,Amer.Geophys.Union,32,450-456.

Gerloff,G.C.,& Skoog,F.(1957): Nitrogen as a limiting factor of Microcystis aeroginsa in Southern Wisconsin Lakes. Ecol.,38,556-564.

Gibson,C.E,&.Stewart,D.A.(1972):Changes in water chemistry of Lough Neagh over a ten year period.Limnol. Oceanog., 17,633-635.

Gillham,R.W.,Webber,L.R.(1969): Nitrogen contaminamination of groundwater by barnyard leachate.J.Water Pollut.Cont.Fed., 41,1752-1762.

Gorham,W.C.(1961): Factors affecting the supply of major ions to inland waters with special reference to the atmosphere. Bull.Geol.Soc.Amer.,72,795-840.

Green,L.A.,&Walker,I.(1970): Nitrate pollution of chalk water. Proc.Soc.Water Tret.Exam.19,169-178.

Griffiths,G.A.P.(1951): Factors influencing nitrate accumulation. in Uganda soils.Empire J.Exp.Agr.19,1-12.

Grimas,U.,Nilsson,N.A.& Wendt,C.(1972): Lake Valtern:effects of exploitation,eutrophication and introductions on salmon communities. J.Fisheries Res. 29.,807-821.

Hagenziker,F.(1957): Soil Nitrogen studies at Urambo,Tanganyika Territory,East Africa. Plant & Soil,9,97-113.

Haith,D.A.(1976): Land use and water quality in New York rivers. J.Env.Engrg.Div.,ASCE EE1,102,1-15.

Hall,F.R.(1970):Dissolved solids - discharge relationships,I Mixing Models.Water Resources Res. 6,845-850.

Harmsen,G.W.(1962): Agricultural and pedological problems of Nitrogen in soil. Landbouwk.Tijdschr.,74,505-519 (in Dutch, English summary).

Harmsen,G.W., & Schreven,D.(1955): Mineralisation of organic Nitrogen in soil; in Norman,A.G.(ed.), Advances in Agronomy, Academic Press, 7, 299-398

Hart,F.C. & King,P.H., & Tchebanoglous,G.(1964): Predictive techniques for water qualityinorganics; J.San. Engrg.Div., A.S.C.E., SA5, 63-67

Hewlett,J.D., & Trondle,C.A.(1975): Non-point and diffused Water Sources: a variable source area problem: Watershed management, Utah State Univ., Logan. A.S.C.E. Sump. 21-46

Hasslet,A.D.(1947): Eutrophication of Lakes by domestic sewage; Ecol. 28, 383-395

Hill,M.J., Hawksworth,G., & Tattersall,G.(1973): Bacteria Nitrosamines and cancer of the stomach; Brit..J.Cancer, 28, 562-576

Hillel,D.(1971): Soil and Water, Academic Press, 288 pp.

Hutchinson,G.E.(1954): The Biochemistry of the Terrestrial Atmosphere in Keiper,G.P. The Earth as a Planet, University of Chicago Press, 371-433

Hutchinson,G.E.(1957): A Treatise on Limnology; Vol. 1, Wiley, New York, 1015 pp.

Hynes,H.B.N.(1960): The Biology of polluted waters; Liverpool 202 pp.

Hynes,H.B.N.(1970): The Ecology of Running Water; Liverpool Univ. Press, 555 pp.

Jaag, O.(1972): Water quality and water pollution control in Switzerland; Biol. Cons., 4, 345-354

Johnson,N.M., Likens,G.E., Bormann,F.H.,Fisher,D.W., & Pearce, R.S.(1969): A working model for the variation in stream water chemistry at Hubbard Brook; Water Res.Res., 5, 1353-1363

Juday,C., & Schloemer,C.L.(1938): Effects of fertiliser on Planktonic production; Prog.Fish.Cult., 40,24-36

Junge,C.E.(1954): The chemical composition of atmospheric aerosols, I, measurements at Round Hill Field Station, June-July, 1953. J.Meterology,VII,323-333

Junge,C.E.(1958): The distribution of ammonia and nitrate in rain-water over the United States; Trans.Amer. Geophys. Union, 39, 241-248

Junge,C.E., & Manson,J.E.(1961): Stratospheric Aerosol Studies; J.Geophys Res., 66, 2163-2182

Kirkby,M.J.(1975): Hydrograph Modelling Strategies, in Processes in Physical and Human Geography: Bristol Essays, (eds) Peel, R., Chisholm, M., Haggett,P., Heinemann, 69-90

Kohl,D.H., Shearer,G.B., & Commoner,B.(1971): Fertiliser Nitrogen: Contribution to Nitrate in Surface water content in a Corn Belt watershed; Sci., 174, 1331-1334

Kohnke,H.(1941): Runoff Chemistry - an undeveloped branch of soil science; Soil Sci.Soc.Amer.Proc., 6, 492-500

Kolenbrander,G.J.(1972): The eutrophication of surface water by agriculture and urban population; Skikstof, 15, 56-67

Kolenbrander,G.J.(1975): Nitrogen in organic matter and fertiliser as a source of pollution, in Proc.Int.Assoc. Water Pollut.Res Specialised Conf., Nitrogen as a Water Pollutant, Copenhagen, 1975

Larson,O., & Hettick,G.(1956): Mineral Composition of rainwater, Illinois State Water Survey, Circular 56

Ledbetter,J.O., & Gloyna,E.F.(1964): Predictive Techniques for Water Quality Inorganics; J.Sanit.Engrg.,Div. ASCE, 381OSA1: 127-151

Ledger,D.L.(1972): The Warwickshire Avon; Trans.Inst.Brit.Geogr. 55, 83-110

Legrand,H.E.(1965): Patterns of contaminated zones of water in the ground Water Res, Res. 1, 83-95

Lester, W.F.(1967): Pollution in the river Trent and its tributaries and related problems of regeneration; J.Inst. Water Engineers, 21, 261-274

Linsley,R.K., Kohler,M.A., & Paulhus,J.L.(1975): Hydrology for Engineers, McGraw Hill, 482 pp.

Marshall,T.J.(1959): Relations between water and soil; Commonwealth Agricultural Bureau

Massey,H.F., & Jackson,M.L.(1952): Selective erosion of fertility consituents; Soil Sci.Soc.Amer.Proc., 16 353-356

Miller,D.G., & Short,C.S.(1972): The Trent Research Programme Vol. 5, Costs of River Water Treatment, Water Res.Board, Reading, 94 pp.

Miller,W.J.(1971): The contribution of storm water discharges to the pollution of surface water; Gas-u-Wass Fach, 112, 15-17 (in German)

Minder,L.(1943): Neuere Untersnachungen uber der Sanerstoffgehatt und die Eutrophie des Zurichsees; Arch.f.Hydrol., 40, 279-301

Minshall,N.E.(1970): Stream enrichment from farm operations, J. Sanit.Engrg.Div,ASCE, 96, SA2, 513-524

Moe,P.G., Mannering,J.V., & Johnson, C.B.(1970): Comparison of losses from Urea and Ammonium Nitrate in surface waters; Soil Sci., 105, 428-433

Nash,J.E., & Sutcliff,J.V.(1972): River flow forecasting through conceptual models Part 1 - A discussion of principles; J.Hydrol., 10, 282-290

Newsome,D.H., Bowden,K., & Green,J.A.(1972): Trent Mathematical Model (a) construction; IWE Birmingham Symp. on Advanced Techniques in River Basin Management, 151-167

Norton,T.E., & Hansen,R.W.(1969): Cattle feedlot Water Quality Hydrology, Cornell University, Conference on Agricultural Waste Management, 203-216

Odum,H.T.(1956): Primary production in flowing waters; Limnol. Oceanog., 1, 102-117

Oliff,W.D., & King,J.L.(1964): Hydrological studies on the Tugela River system; Part IV. The Mooi River Hydrobiologica, 24, 567-583

Owens,M.(1970): Nutrient balances in rivers; Water Treat. and Exam., 19, 239-252

Owens,M., & Edwards,R.H.(1970): A chemical survey of some English rivers; J.Water Treat. and Exam., 13, 134-144

Owens,G.E., & Johnson,M.G.(1966): Publication number 15; Great Lakes Division, Univ. of Michigan, 400 pp.

Palmer,C.M.(1962): Algae in water supplies: Public Health Service Pub. No. 657, Washington,D.C.

Porter,K.S., & Boon,A.G.(1971): Cost of waste water with particular reference to the river system of the Trent area; IWPC Nottingham Symp. on the Trent Res. Prog., 56-73

Rensink,J.H.(1966): The influence of the discharge of dairy waste on surface waters; Sewage & Ind. Wastes, 30, 1213-1219

Rich,L.G.(1973): Environmental Systems Engineering, McGraw Hill, New York, 448 pp.

Rogers,H.T.(1941): Plant nutrient losses from erosion from rotation on silt loam; Soil Sci. Soc. Amer. Proc., 6, 263-271

Russel,E.J., & Richards,E.H.(1919): The amount and composition of rainfalling at Rothampsted; J.Agric.Soc., 9, 309-337

Sawyer,C.W.(1947): Fertilisation of lakes by agricultural and urban drainage; J.New England Water Works Assoc., 61-109-127

Sawyer,C.W.(1962): Causes effects and control of aquatic growths; J.Water Pollution Cont.Fed., 34, 279-285

Schwinn,D.E., & Dickson,B.H.(1972): Nitrogen and Phosphorus variations in domestic wastewater; J. Water Poll.Cont.Fed., 44, 2059-2065

Shannon,E.E., and Brezonik,P.L.(1972): Eutrophication analysis - a multivariate approach; J.San.Eng.Div.ASCE SA1, 98, 37-57

Sherwani,J.K.(1971): Effects of low flow hydraulic regimes on water quality management; N. Carolina Water Res. Res. Inst., Rayleigh, UNC-WRRI-71-26

Shutt,F.T., & Hedley,B.(1925): The nitrogen compounds in rain and snow; Proc.Roy.Can.Inst.Ser.III, 19, 1-10

Smith,G.E.(1967): Contamination of water by Natrates, J.Nat.Fert. Assoc. (May-June)

Steel,T.D.(1972): Digital computer applications in chemical quality studies of surface water in a small watershed; Int.Assoc.Sci.Hydrol., Pub. 80, 203-214

Stewart,B.A.(1968): Agriculture's effect on Nitrate Pollution of Groundwater; J.Agric.Soc., 58, 145-152

Sussex River Authority (1968): Water for Sussex; 1st Periodic Survey, Section 14, Sussex River Authority

Sylvester,R.(1961): Nutrient content of drainage water from forested, urban and agricultural watersheds; Trans. Seminar on Algae and Metropolitan Wastes, ed. Taft,R.A., San.Eng.Centre TR-W61-3, 80-87

Sylvester,R.O., & Anderson,G.R.(1964): A lake's response to its environment; J.San.Eng.Div.ASCE 90, 1-22

Sylvester,R.O., & Seabloom,R.W.(1963): Quality and significance of irrigation return flow; J.Irrig.Div.ASCE 89, 1-27

Taylor,A.W., Edwards,W.M., & Simpson,E.E.(1971): Nutrients in streams draining woodland and farmland near Coshooton, Ohio, Water Res.Res., 7, 81-89

Thomas,E.A.(1962): The eutrophication of rivers and lakes; causes and prevention; Trans. 3rd Seminar on Biol. Problems in Water Pollution, (ed.) Taft,R.A., San.Eng. Centre, Pub. 999-WP-25

Thomas,L.C., & Chamberlain,G.J.(1967): Colorimetric Chemical Analytical Methods, 7th edit. The Timtometer Ltd., Salisbury, 626 pp.

Thomes,J.B. & Clark,M(1975): A review of some applications of stochastic empirical modelling in water quality; Non-sequential water quality project paper 2, London School of Economics, 14 pp.

Timmons,D.R., Holt,R.F. and Latteral,J.J.(1970): Leaching of crop residues as a source of nutrients in surface waters; Water Res.Res., 6, 1367-1375

Tinker,J.(1971): The Smug and Silver Trent; New Sci., June, 614-618

Tirabassi,H.A.(1971): A statistically based mathematical water quality model for non-esturine river systems; Water Res. Bull., 7, 1221-1237

Tisdale,E.S.(1931): Epidemic of intestinal disorders in Charlestown, W. Virginia, occurring simultaneously with unpredicted water supply problems; Amer. J.Pub.Health., 21, 198-214

Tomann,R.V.(1967): Rime series analysis of water quality data; J. San.Eng.Div.,ASCE, 93, SA1, 1-23

Tomann,R.V.(1970): Variability of waste treatment plant performances; J.San.Eng.Div.,ASCE, 96, SA3, 819-837

Tomlinson,T.E.(1970): Trends in nitrate concentrations in English Rivers in relation to fertiliser use; J.Water Tret. and Exam., 19, 277-293

Veldee,M.V.(1931): Epidemological Study of suspected water borne gastroenteritus; Amer.J.Pub.Health, 21, 1227-1239

Viets,F.G.(1961): Agronomic need for secondary and microelements Assoc.Amer.Fert.Cont.Off.Office Pub. No. 15, 59-63

Virtanen,A.I.(1952): Molicular nitrogen fixation and nitrogen cycle in nature: Tellus, 4, 304-306

Vollenweder,R.A.(1968): Scientific fundamentals for the eutrophication of lakes and flowing waters with particular reference to nitrogen and phosphorus as a factor in eutrophication

Wadleigh,C.H.(1968): Wastes in relation to agriculture and forestry; US Dept. of Agr.Misc.Pub. No. 1065, 112 pp.

Wagner,G.I.(1970): The increase in the pollution load of Lake Constance; Gas-u-Wass.Fach.,v.III, 485-487. (in German)

Walling,D.E., & Webb,B.W.(1975): Spatial variation in river water quality: a survey of the R.Exe; Inst.Brit.Geog., Trans., 65, 155-171

Water Resources Board (1973): Trent Research Programme, Vol. 1, Rept. of the Water Resources Board, HMSO, London

Webb,B.W., & Walling,D.E.(1974): Local variations in background water quality: The Science of the Total Environment, 3, 141-153

Webber,L.R., & Lane,T.H.(1969): The nitrogen problem in the land disposal of liquid manure; Cornell Univ.Conf. on Agricultural Waste Management, 124-130

Weibel,S.R., & Anderson,R.J., & Woodward,R.L.(1964): Urban land runoff as a factor in stream pollution; J.Water Poll.Cont.Fed. 36, 914-923